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FLIGHT SIMULATOR EXPERIMENTS AND ANALYSES IN SUPPORT OF FURTHER DEVELOPMENT OF MUL-F-83300 V/STOL FLYING QUALITIES SPECIFICATION

Edward W. Vinje, et al

United Aircraft Research Laboratories

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The results indicate that the MIL-F-83300 Level 1 requirement for V/STOL dynamic response provides aircraft dynamics which remain controllable for nominal increases in gust intensity. The specification appears to generally exclude pitch and roll control lags, and lags in thrust response, which cause unsatisfactory flying qualities; it admits lags for which pilot opinion does not deteriorate. However, it excludes directional control lags which do not degrade opinion. The results further indicate that the specification for installed control moments provides levels which are satisfactory but not excessive. Control sensitivities selected by the pilots also generally fall within the boundaries specified, but are much closer to the lower limit than to the upper. Finally, data from the height control study show that minimum Z_W levels of

241

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13. Abstract (Continued) -0.25 to -0.35 are necessary for satisfactory flying qualities with unlimited T/W.

Results for unconventional control techniques evaluated indicate that rotor-propulsion system stored energy can be used to offset limitations in installed control power. Independent thrust-vector control can be used for hovering and maneuvering when properly implemented. Rate-command/attitude-hold control does not appear to provide benefits for hover and low-speed flight.

The exceedance data show that speed-stability and damping are the configuration parameters having the greatest effects on control power usage. Control system lags have little effect on pitch and roll control-moment usage, but they increase yaw control-moment and thrust usage somewhat. The largest amounts of control moment were used for the quick stop task; the smallest amounts were used for hover and turn-over-a-spot. The data indicate that the installed total moment for pitch plus roll control must be sufficient to account for simultaneous usage by the pilot; it cannot be assumed that pilots make independent pitch and roll control inputs.

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DD FORM 1 NOV 65 1473 (BACK)
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FOREWORD

This report was prepared for the United States Air Force by the United Aircraft Research Laboratories, East Hartford, Connecticut.

The work reported herein was performed by the United Aircraft Research Laboratories under the sponsorship of the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The research was conducted under Subcontract S-72-4 to Calspan Corporation (formerly the Cornell Aeronautical Laboratory) as part of Air Force Contract F33615-71-C-1722, Project 643A. The AFFDL project engineer was Mr. Terry Neighbor (AFFDL/FGC) and the Calspan project engineer was Mr. David Key.

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C. B. Westbrook
Chief, Control Criteria Branch
Flight Control Division
Air Force Flight Dynamics Laboratory

ABSTRACT

Fixed- and moving-base flight simulator experiments and analyses were conducted to provide data for use in substantiating, refining and extending the hovering and low-speed-flight portion of MIL-F-83300 - V/STOL Flying Qualities Specification. For longitudinal and lateral control, the following areas were investigated: turbulence intensity, control lags and delays, control-moment limits, control moments through stored energy, inter-axis motion coupling, independent thrust-vector control and rate-command/attitude-hold control. For height and directional control, the effects of damping levels, control lags and delays, and control power limits were investigated. Opinion ratings, pilot comments, and pilot-selected control sensitivities were recorded in the flight simulator experiments; control-power-usage data were also obtained.

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Results for unconventional control techniques evaluated indicate that rotor-propulsion system stored energy can be used to offset limitations in installed control power. Independent thrust-vector control can be used for hovering and maneuvering when properly implemented. Rate-command/attitude-hold control does not appear to provide benefits for hover and low-speed flight.

The exceedance data show that speed stability and damping are the configuration parameters having the greatest effects on control power usage. Control system lags have little effect on pitch and roll control-moment usage, but they increase yaw control-moment and thrust usage somewhat. The largest amounts of control moment were used for the quick stop task; the smallest amounts were used for hover and turn-over-a-spot. The data indicate that the installed total moment for pitch plus roll control must be sufficient to account for simultaneous usage by the pilot; it cannot be assumed that pilots make independent pitch and roll control inputs.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

SYMBOLS

BC1-BC6	Basic V/STOL aircraft configurations 1 through 6 (see Table I)
C_1, C_2, C_3	Coefficients used in nonlinear representation for control moments available through rotor-propulsion system stored energy (see Eq. (1))
CM_m	Maximum pitch, roll and yaw moments available for control, rad/sec^2
CM_{SE}	General notation for control moments available through stored energy, rad/sec^2
$\overline{CM}_5$	Average pitch, roll and yaw control moments exceeded 5-percent of the time with unlimited moments available, rad/sec^2
d_e, d_a	Time delays in pitch and roll response, respectively, to control inputs, sec
d_n	Time delay in thrust response to collective control input
g	Gravitational constant, 32.2 ft/sec^2
HOV	Designates hover subtask
I_x, I_y, I_z	Moments of inertia in roll, pitch and yaw, slug-ft^2
j	$\sqrt{-1}$
L_c	Roll control moment commanded by pilot and SAS divided by I_x, rad/sec^2
L_{c_m}	Maximum available L_c, rad/sec^2
L_{c_o}	Reference value of L_c, rad/sec^2
$\bar{L}_{c_o}$	Averaged L_{c_o}, rad/sec^2
L_p	Roll rate damping divided by I_x, per sec
L_q	Rolling moment due to pitch rate divided by I_x, per sec

SYMBOLS (Cont'd)

L_{v_g}	Lateral speed-stability parameter divided by I_x, per sec^3
L_{δ_a}	Lateral control sensitivity divided by I_x, (rad/sec^2)/in.
L_{δ_e}	Rolling moment due to longitudinal control stick input, (rad/sec^2)/in.
L_{ϕ}	Roll attitude stabilization divided by I_x, per sec^2
m	Aircraft mass, slugs
MAN	Designates entire maneuvering subtask, i.e., motion in both the x and y directions
M_c	Pitch control moment commanded by pilot and SAS divided by I_y, rad/sec^2
ΔM_c	Increment to pitch control moment available through rotor-propulsion system stored energy, rad/sec^2
M_{c_m}	Maximum available M_c, rad/sec^2
M_{c_o}	Reference value of M_c, rad/sec^2
$\overline{M}_{c_o}$	Averaged M_{c_o}, rad/sec^2
M_{c_5}	Pitch control-moment level exceeded 5-percent of the time with unlimited moment available divided by I_y, rad/sec^2
M_p	Pitching moment due to roll rate divided by I_y, per sec
M_q	Pitch rate damping divided by I_y, per sec
$\dot{M}_{TS}$	Commanded rate-of-change of pitch control moment for thumb switch input, (rad/sec^2)/sec
M_{u_g}	Longitudinal speed-stability parameter divided by I_y, per sec^3
M_{δ_a}	Pitching moment due to lateral control stick input, (rad/sec^2)/in.
M_{δ_e}	Longitudinal control sensitivity divided by I_y, (rad/sec^2)/in.

M_θ	Pitch attitude stabilization divided by I_y, per sec^2
N_c	Yaw control moment commanded by pilot and SAS divided by I_z, rad/sec^2
N_{c_5}	Yaw control-moment level exceeded 5-percent of the time with unlimited moment available divided by I_z, rad/sec^2
N_{c_m}	Maximum available N_c, rad/sec^2
N_r	Yaw rate damping divided by I_z, per sec
N_v	Yaw-due-to-lateral-velocity parameter divided by I_z, rad/(ft-sec)
N_{δ_r}	Yaw control sensitivity divided by I_z, (rad/sec^2)/in.
PR	Pilot opinion rating based on Harper-Cooper scale
ΔPR	Degradation in pilot rating
P_{LL}	Percent time commanded roll moment exceeded installed roll control moment, percent
P_{ML}	Percent time commanded pitch moment exceeded installed pitch control moment, percent
P_{NL}	Percent time commanded yaw moment exceeded installed yaw control moment, percent
P_{SL}	Percent time simultaneous pitch and roll moment commands exceeded the sum of the installed pitch and roll control moments, percent
P_{TL}	Percent time commanded thrust exceeded installed thrust, percent
QS	Designates entire quick-stop subtask, i.e., motion in both x and y directions
s	Laplace operator, 1/sec
SAS	Stability augmentation system
S_{u_g}, S_{v_g}	Power spectrum of longitudinal and lateral turbulence components, respectively, ft^2/sec

$t_{\ddot{\theta}_{max}}, t_{\ddot{\phi}_{max}}, t_{\ddot{\psi}_{max}}$	Time interval following control input for pitch, roll and yaw, respectively, within which MIL-F-83300 (paragraph 3.2.4, Ref. 1) stipulates that maximum initial angular acceleration shall occur, 0.3 sec
TS	Thumb-switch thrust-rotation command, 0 or ±1 (+1 is aft)
TU	Designates ±180 deg turn subtask
T/W	Thrust-to-weight ratio
$(T/W-1)_5$	Five-percent incremental T/W usage level, g's
$\Delta T/W$	Increment to thrust-to-weight ratio, g's
UL	Notation for effectively unlimited control moment or thrust level
U_m	Mean wind from the north (000 deg true), 10 kts
x	Conventional longitudinal axis notation in the body-axis system, ft
XM	Designates x-direction part of the maneuver subtask
XQS	Designates x-direction part of the quick-stop subtask
X_u	Longitudinal drag parameter divided by m, per sec
y	Conventional lateral-axis notation in the body-axis system, ft
YM	Designates y-direction part of the maneuver subtask
YQS	Designates y-direction part of the quick-stop subtask
Y_{P_h}	Pilot model transfer function for height control loop
Y_{P_θ}	Pilot model transfer function for pitch control loop
Y_{P_ψ}	Pilot model transfer function for yaw control loop
Y_v	Lateral drag parameter divided by m, per sec
Z_w	Height velocity damping divided by m, per sec

SYMBOLS (Cont'd)

$Z_{w_a}, Z_{w_s}, Z_{w_T}$	Notation for aerodynamic, stability augmentation system and total Z_w, respectively, per sec
Z_{δ_c}	Height control sensitivity divided by m, (ft/sec^2)/in.
$\dot{\gamma}$	Thrust-vector-rotation rate, deg/sec
γ_{δ_e}	Thrust-vector angle per inch of control input, deg/in.
δ_c	Collective control displacement, in.
ζ	Damping ratio of oscillatory roots
ζ_a, ζ_e	Damping ratios of second-order lags in roll and pitch response to control inputs, respectively
θ	Euler pitch attitude angle, rad
σ_{u_g}	RMS longitudinal turbulence, ft/sec
σ_{v_g}	RMS lateral turbulence, ft/sec
τ_a, τ_e	Time constant for first-order lag in roll and pitch control response, respectively, sec
τ_h	Time constant for first-order lag in thrust response to collective control input, sec
τ_Δ	Time constant for decay of incremental control power available through stored energy, sec
τ_ψ	Time constant for first-order lag in yaw response to pedal input, sec
ϕ	Euler roll attitude angle, rad
ψ	Euler yaw attitude angle, rad
ω_d	Damped frequency of the aircraft attitude (pitch or roll) oscillatory roots, rad/sec
ω_n	Natural frequency of the aircraft attitude (pitch or roll) oscillatory roots, rad/sec
$\omega_{n_a}, \omega_{n_e}$	Natural frequencies of second-order lag in roll and pitch response to control inputs, respectively, rad/sec

SECTION I

INTRODUCTION

A specification for V/STOL aircraft flying qualities, MIL-F-83300, has recently been developed under Air Force sponsorship (Ref. 1). It is based on the results of an extensive evaluation of previous V/STOL flying qualities studies as well as the findings of recent experimental and analytical research funded by the Air Force. Most of the latter was conducted as part of the VTOL Integrated Flight Control System (VIFCS) program. The specification and its supporting documentation provide guidance in the design of V/STOL aircraft control systems as well as a standard for flying qualities. They also are the culmination of research which represents a major advance in the understanding of V/STOL flight characteristics.

Additional research is required, however, in the V/STOL hover and low-speed flight regime. In particular, general information is needed on requirements for installed control power, i.e., control moments and thrust-to-weight ratio. Providing appropriate levels of control power for hover and low-speed flight is a critical part of the design of V/STOL aircraft. Despite its importance, there are little general data available which relate flying qualities to installed control power (Refs. 2 through 4). A related factor which has received almost no attention is the incremental control moment or thrust which can be obtained from rotor-propulsion system stored energy. By temporarily converting a part of the rotor-propulsion system angular momentum to control power, it is possible to supplement the installed control powers. Other general areas which should be investigated further are control lags and delays and inter-axis motion coupling. Motion coupling in particular has not been given adequate attention. Control and rate coupling, for example, exist to some degree in almost all V/STOL aircraft and their effects can lead to a significant degradation in flying qualities. In general, however, the specification treats motion coupling only qualitatively.

An uncertainty also exists over the level of height velocity damping, Z_w, needed for satisfactory height control characteristics. MIL-F-83300 indicates that height control will be satisfactory providing that Z_w is not positive, i.e., not destabilizing. Results which support this contention can be found (Ref. 5), but data which indicate a requirement for a significant level of negative Z_w are also available (Refs. 6 and 7). The height control portion of the specification also assumes that a tradeoff exists between the level of height velocity damping present in the aircraft and the required installed thrust-to-weight ratio. Although there are results which support this assumption, it merits further substantiation. Finally, MIL-F-83300 would be more useful if its scope could be extended to encompass

some unconventional V/STOL control systems. The specifications may already apply to many aspects of hover and low-speed flight with such systems. However, its limitations in this regard are not known and it would be beneficial to examine V/STOL flying qualities with several unconventional systems that might be used on future aircraft. Examples of these types of systems are rate-command/attitude-hold or "stick steering" control and thrust-vector control independent of aircraft attitude.

The study described in this report provides additional information on the hovering and low-speed flying qualities of V/STOL aircraft. The objective of the program was to provide experimental flight simulator data and analyses which will be used to substantiate, refine, and extend the hovering and low-speed flight portion of the V/STOL Flying Qualities Specification.

SECTION II

BACKGROUND OF EXPERIMENTAL PROGRAM

This section contains a description of the studies conducted using the UAC V/STOL Flight Simulator and a discussion of the equipment and procedures used in the experimental program. Most of the equipment and many of the procedures used for the experimental studies were similar to those described in Refs. 7 and 8. Also, the flight simulation for this study was designed to correspond as closely as possible to that implemented at Norair for their previous VIFCS study (Ref. 9). Table A-I is a summary of parameters for cases evaluated and a key to tables in Appendices A, B, C and D that are tabulations of all the data discussed in Sections III through V. Additional details of the flight simulation are contained in Appendix F.

A. Flight Simulator Studies

The experimental program was designed to provide data to substantiate, refine and extend the hovering and low-speed flight portion of the V/STOL Flying Qualities Specification. It included studies of longitudinal and lateral flying qualities, height control and directional control. Emphasis was placed on obtaining information related to requirements for installed control power. The data obtained generally consisted of pilot opinion ratings, pilot-selected control sensitivities and measured control moment and/or thrust usage.

1. Longitudinal and Lateral Control

There were seven different investigations conducted in this part of the program. They were concerned with the effects of (1) turbulence intensity, (2) lags and delays in the response to control inputs, (3) limits on the available control moments, (4) incremental pitch control moment through stored energy, (5) inter-axis motion coupling, (6) thrust-vector control independent of aircraft attitude, and (7) rate-command/attitude-hold control. Six basic V/STOL configurations were selected. A range of values of the parameter being considered was then evaluated for each basic configuration. Also, longitudinal and lateral control were generally evaluated together; only one pilot opinion rating was given for a test case, and this represented the pilot's assessment of the combined longitudinal and lateral flying qualities. In addition, control moments were effectively "unlimited" and pitch, roll and yaw control-moment usage was measured for each study, unless noted otherwise.

a. Basic Configurations

The six basic configurations had conventional rate and attitude stability augmentation, and each was similar to configurations evaluated in the previous Norair and UARL studies (Refs. 7 through 9). They also were symmetrical in that each lateral stability derivative had the same value as the corresponding longitudinal derivative. The directional and vertical stability derivatives were the same for all six configurations. Table I lists their stability derivatives and root locations; roots are also plotted in Fig. 1. It is apparent that the basic configurations span a wide range of dynamic response characteristics. They encompass all three of the levels (1, 2 and 3)* used to characterize aircraft flying qualities in MIL-F-83300, in addition to exhibiting a range of responses to turbulence.

TABLE I

STABILITY DERIVATIVES AND ROOT LOCATIONS FOR UARL BASIC CONFIGURATIONS

Conf.	Level	Stability Derivatives[1,2]				Root Locations	
		$M_u g$	X_u	M_q	M_θ	Real Root	$-\zeta\omega_n \pm j\omega_d$
BC1	1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81 ± j 1.85
BC2	2	1.0	-0.05	-1.1	-2.5	-0.5	-0.30 ± j 1.47
BC3	3	1.0	-0.05	-2.0	0	-2.2	0.08 ± j 0.68
BC4	1	1.0	-0.20	-3.0	-1.7	-2.5	-0.35 ± j 0.64
BC5	1	0.33	-0.20	-1.7	-4.2	-0.29	-0.81 ± j 1.85
BC6	2	1.0	-0.20	-1.1	-2.5	-0.65	-0.32 ± j 1.48

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivatives.

2. Directional derivatives for all configurations: $N_v = 0.002$, $N_r = -1$, $N_{\delta_r} = 0.20$; Vertical derivatives: $Z_w = -1$, $Z_{\delta_c} = -3.2$, $T/W > 1.15$.

*Level 1 flying qualities are "clearly adequate for the mission"; Level 3 are such that the "aircraft can be controlled safely but pilot workload is excessive or mission effectiveness is inadequate, or both"; and Level 2 flying qualities lie between these extremes.

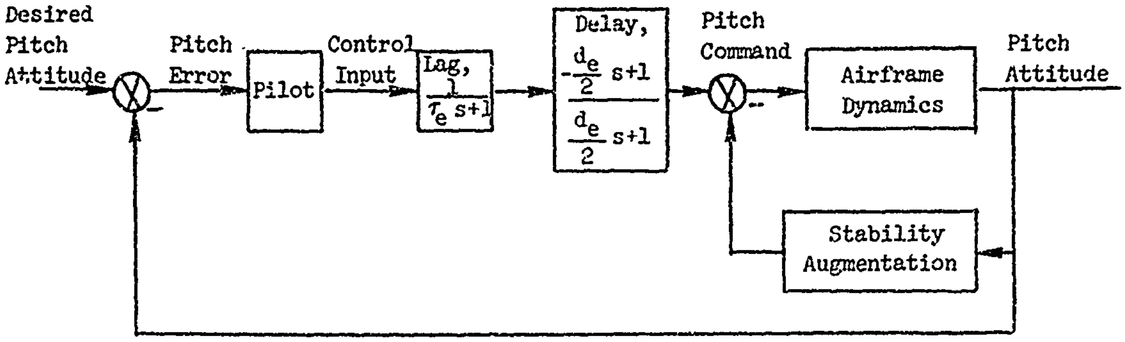
Configurations BC1, BC4 and BC5 are Level 1, but BC4 exhibits a larger attitude response to turbulence ($M_u g = -L_v g = 1.0$) than BC1 and BC5 ($M_u g = -L_v g = 0.33$). Also, BC4 and BC5 have greater position responses to turbulence than BC1 ($X_u = Y_v = -0.20$ versus $X_u = Y_v = -0.05$). Configurations BC2 and BC6 are Level 2 with large speed-stability parameters. This feature, combined with the lower levels of damping, results in significant attitude disturbances due to gusts. Configuration BC6 also has the large drag parameters and the attendant large position responses to turbulence. Finally, configuration BC3 is Level 3 with lightly damped dynamics, large speed-stability parameters ($M_u g = -L_v g = 1.0$), and large attitude disturbances from turbulence. It is important to note also that all of the rate damping and attitude stabilization represented by these derivatives in Table I (i.e., M_q, M_θ and their lateral, vertical and directional counterparts) was assumed to be provided by a stability augmentation system (SAS).

b. Turbulence Intensity

This study was conducted to provide information on the sensitivity of aircraft with different level flying qualities to changes in turbulence intensity and to obtain control-moment usage data. The flying qualities of Level 1 aircraft should be somewhat insensitive to gust level. That is, the MIL-F-83300 definition for V/STOL Level 1 dynamic response must be formulated such that flying qualities remain acceptable for commonly encountered turbulence intensities. Greater deterioration in flying qualities would be expected for Level 2 and 3 aircraft. Each of the six basic configurations was evaluated at three levels of rms longitudinal and lateral turbulence intensity, $\sigma_{u_g} = \sigma_{v_g} = 3.4$, 5.8 and 8.2 ft/sec. The wind simulation also included a mean wind $U_m = 10$ kt (≈ 17 ft/sec) from the north. Note that only for this study were rms turbulence intensities other than $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec evaluated. For the rest of the program the wind simulation consisted of $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec and $U_m = 10$ kt. Details of the wind simulation are described in Section II.B.1.

c. Lags and Delays in Attitude Response to Control Inputs

Pitch and roll control lags and delays were evaluated to test the adequacy of the MIL-F-83300 specification for such effects (paragraph 3.2.4, Ref. 1). These lags and delays only operated on the pilot's control stick inputs, i.e., the stability augmentation system (SAS) commands were not affected. The location of the lags and delays in the pitch attitude control loop is shown schematically in Sketch II-A. The implementation was identical for the roll loop. In the specification pitch, roll or yaw lags and delays are presumed to be within acceptable limits if the time to reach the initial maximum angular acceleration is no greater than 0.3 sec. To span this requirement with both acceptable and unacceptable values, first-order lags having time constants of 0.1, 0.3 and 0.6 sec were evaluated for each basic configuration. Also, the longitudinal and lateral lags were always



SKETCH II-A. Location of Lags and/or Delays Simulated in Pitch Response to Control Inputs

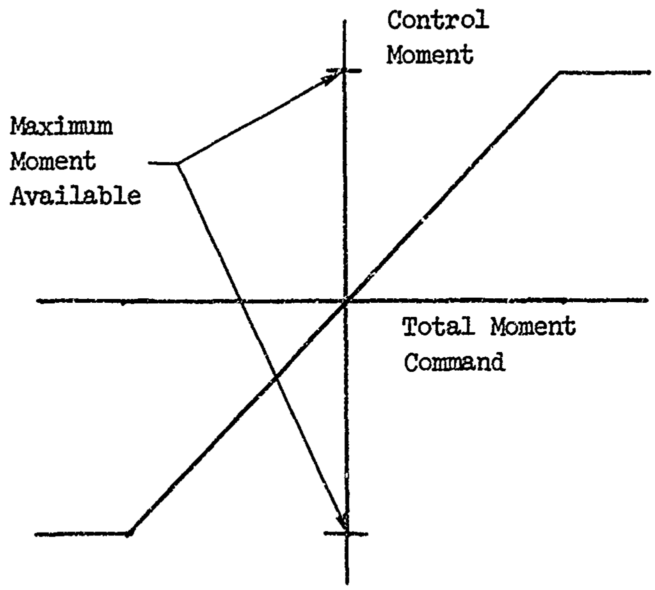
equal ($\tau_e = \tau_a$) for a given test case. In addition, pitch and roll moment delays, $d_e = d_a$, of 0.1 sec were evaluated with and without a combined first-order lag of $\tau_e = \tau_a = 0.3$ sec. Configurations BC1 and BC2 were used for these test cases. The effects of second-order control lags were also investigated with configuration BC1 to further test the specification. The significance of amplitude versus phase effects was examined by varying the damping ratio and natural frequency of the second-order lags.

d. Limits on Available Control Moments

The purpose of the control-moment-limit study was to investigate the effects of aircraft configuration and control system parameters on the total control moments (i.e., moments commanded by the pilot and the rate damping and attitude stabilization derivatives or SAS) necessary for pilot acceptance. Another objective was to examine whether these required installed control moments correlate with the control moment levels exceeded some given small percent of the time with unlimited moment available, e.g., the 5-percent level. Information on the adequacy of the MIL-F-83300 specification for pitch, roll and yaw control power (paragraph 3.2.3.1) was also provided by comparing it with the results of this study.

Configurations BC1, BC4, BC5 and BC6 were considered initially without control lags or delays. Three to five levels of available total control moment were evaluated for each configuration, and pilot opinion ratings were used to indicate the sufficiency of the levels. Pilots were not aware of the control-moment limits except as they affected flying qualities. The moment limits were applied on an analog computer, not to the physical control stick motion and the maximum control travels available were such that the limits would always be exceeded if the maximum travels were used. The control moment versus moment command characteristics simulated in the moment

limit study for pitch, roll and yaw control are shown in Sketch II-B. Note that the moments available in the pitch, roll or yaw axes were never identical. The reference limits or starting points for the installed control-moment levels (pitch, roll and yaw) were averages of those levels exceeded 5 percent of the time (CM_5) with unlimited moment available. The limits for the remaining test cases were developed by increasing (or decreasing) the reference levels by integral multiples of 10 percent.



SKETCH II-B. Pitch, Roll or Yaw Control Moment Versus Total Control-Moment Command Characteristics for the Moment Limit Study

The effects of control-moment limits were next evaluated with control system lags and delays present. Configurations BC1 and BC5 were used with pitch and roll response delays of $d_e = d_a = 0.1$ sec in combination with first-order lags of either $\tau_e = \tau_a = 0.3$ sec or 0.6 sec. The moment limits evaluated and the procedures for this investigation were unchanged from those for no control lags or delays.

e. Control Moments Through Stored Energy

Several types of V/STOL aircraft derive pitch and roll control moments from cyclic and/or collective changes of rotor system blade angles. Momentary incremental control moments above the installed moment levels can be obtained for such systems by abruptly increasing blade angles to values larger than the normal operating limit. Of course, the aircraft's powerplant will be unable to maintain engine rpm at this large blade angle, and rpm will decay. However, the brief increase in moment may be sufficient

to compensate for deficiencies in the installed control moments. This study was undertaken to examine whether the stored energy in typical V/STOL rotor-propulsion systems could be used to such advantage.

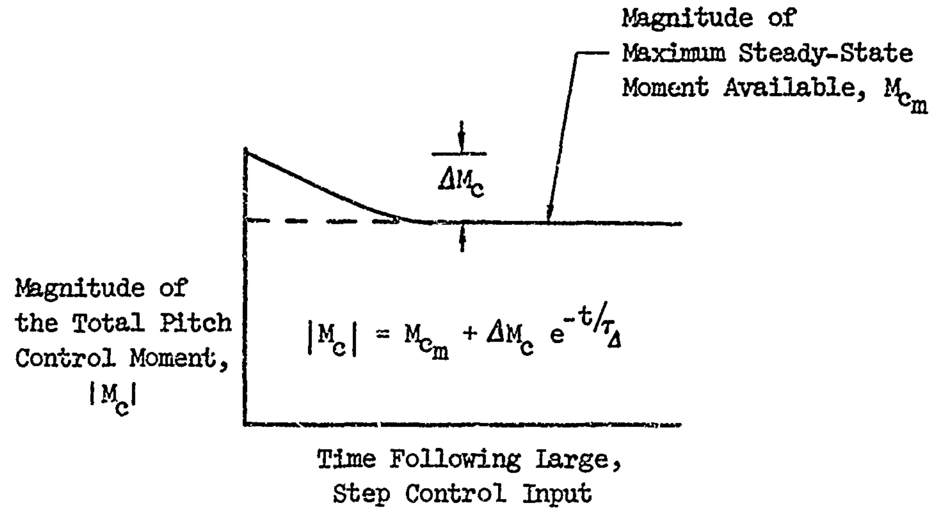
Preliminary analyses indicate that it may be possible to approximate the control moments available from stored energy, CM_{SE}, by

$$\frac{d(rpm)}{dt} + C_1\ (rpm)^2 = C_2$$
$$CM_{SE} = C_3\ (rpm)^2 \tag{1}$$

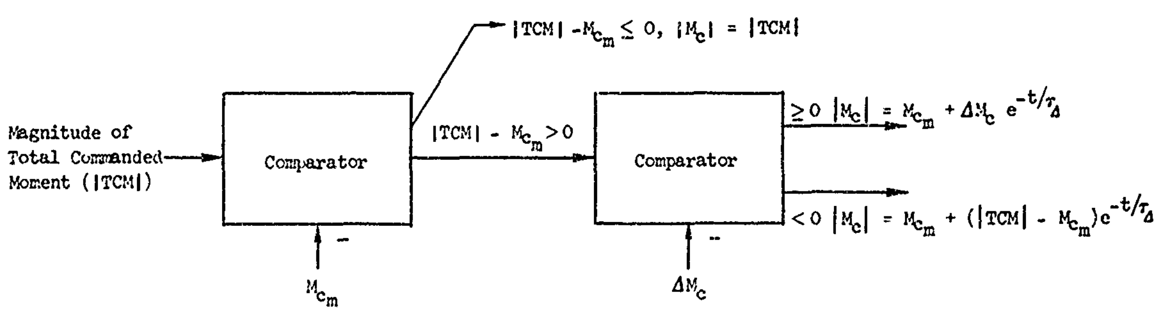
where coefficient C_1 is related to the blade drag, C_2 to the available engine horsepower, and C_3 to the blade lift coefficient. Also, coefficients C_1 and C_3 both change when the pilot moves his control stick. For this study, stored energy effects were simulated for pitch control moments only and a linearized version of Eq. (1) was used to represent stored energy (Eq. (2)).

$$\tau_\Delta\ \frac{d}{dt}\ (CM_{SE}) + CM_{SE} = \tau_\Delta\ \frac{d}{dt}\ (\,|\text{Commanded Moment}| - M_{c_m}) \tag{2}$$

In Eq. (2) the parameter τ_Δ is the time constant associated with the stored energy decay and M_{c_m} is the steady-state or installed control moment. Also, the maximum control moment increment available from stored energy is defined as ΔM_c and the function $(|\text{Commanded Moment}| - M_{c_m})$ in Eq. (2) cannot be larger than ΔM_c. In addition, the stored energy increment was available for both positive and negative control commands as indicated in Eq. (2). The pitch control-moment step response for the stored energy study is shown in Sketch II-C. The moment response shown there is similar to the maximum pitch control moment the pilot and/or SAS could command if a large, rapid control input was made and sustained. The total moment available, then, consisted of a continuously available installed moment, M_{c_m}, plus a transient term which was excited if the magnitude of the total command exceeded M_{c_m}. The transient gave an abrupt increase related to the $|\text{Commanded Moment}| - M_{c_m}$ (up to the maximum increment of ΔM_c) that decayed with time constant τ_Δ. M_{c_m} and ΔM_c are considered to be positive functions in this discussion. The increment from stored energy could be used at any time, but after it decayed the pilot (and/or SAS) had to reduce the commanded moment and wait until the stored energy simulation recovered (the recovery time constant was also τ_Δ). This effectively simulated the time it would take a propulsion system to restore rotor rpm. A logic diagram illustrating the stored-energy simulation is shown in Sketch II-D. Representative values for the increment and the rpm decay (and recovery) time were determined from an analysis of the XC-142



SKETCH II-C. Step-Response Characteristics of the Simulation of Incremental Control Moment Available Through Stored Energy



SKETCH II-D. Schematic Showing Switching Logic for Stored Energy Simulation

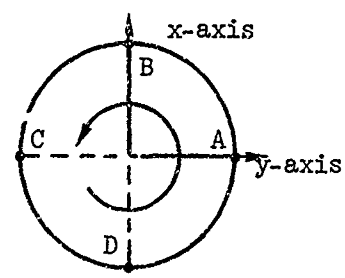
propulsion system. It appears that a moment increment of 30 percent of the installed moment is possible with associated decay time constants of τ_Δ = 0.05 and 0.10 sec. Values for τ_Δ of as much as 0.2 sec may be possible for helicopters because of the greater rotor-system inertia.

The effects on flying qualities of pitching moment available through stored energy were investigated with the same basic configurations considered in the control-moment limit study, i.e., BC1, BC4, BC5 and BC6. The installed pitch control moment, M_{c_m}, for each configuration was set at a low level

which yielded unsatisfactory pilot ratings without stored energy effects. All other installed control moments were set at satisfactory levels. The effects of the incremental pitch control moments supplied by stored energy were then evaluated for different combinations of ΔM_c and τ_Δ. Pilot ratings were used to assess the effects of stored energy. As for the study of control-moment limits, the pilots were not aware of the limits on pitch control power except through aircraft flying qualities. Control-moment data were not measured during the stored energy investigation.

f. Inter-Axis Motion Coupling

This study was performed to determine acceptable values of attitude rate coupling (M_p and L_q) and control coupling (M_{δ_a} and L_{δ_e}). An analysis was conducted initially to determine appropriate polarities and magnitudes for these parameters. The sign convention used for the attitude rate coupling (M_p positive and L_q negative) was derived from a simple analysis of hingeless-rotor aerodynamics. When the rotor tip-path-plane shown in Sketch II-E



SKETCH II-E. Top View of Rotor Tip Path Plane

undergoes pitch rates, one effect gives rise to net rolling moments. For example, if pitch attitude is increased by a positive pitch rate, the angle of attack of a blade in arc DAB will also increase, while that in arc BCD will decrease, causing a negative rolling moment (L_q negative). Similarly, a positive roll rate (increase in roll attitude) results in a positive pitching moment (M_p positive). Data in Ref. 10 indicate that rate coupling levels ranging from M_p = 0.3, L_q = -2.7 to M_p = 1.5, L_q = -14 can be present in uncompensated helicopter control systems, depending on rotor design.

The sign convention for control coupling can also be interpreted by reference to Sketch II-E. The maximum control moment for an articulated (hinged) rotor occurs when the blade has moved an additional 90 deg after a blade-angle (cyclic) change, i.e., the maximum pitching moment occurs at point B if the blade angle is changed at A. For a hingeless rotor the

maximum moment occurs after a smaller phase lag, e.g., somewhere in the arc AB for a blade angle change at A. Therefore, a positive pitch control input gives rise to a negative roll moment ($L_{\delta_e} < 0$) and a positive roll control command results in a positive pitch moment ($M_{\delta_a} > 0$). It should be noted that, with the sign conventions described, the effects of attitude rate and control coupling are additive. For example, a positive pitch control input yields a positive pitch rate and, since both L_q and L_{δ_e} are negative, the induced rolling moments from both sources are negative. However, in the flight simulator evaluation of coupling effects, coefficients having signs which resulted in cancelling moments ($L_q < 0$, $L_{\delta_e} > 0$ and $M_p > 0$, $M_{\delta_a} < 0$) were also evaluated.

Configurations BC1 and BC2 were considered in this study with rate coupling levels of $M_p = -L_q = 2$ and 4 and control coupling up to $M_{\delta_a}/L_{\delta_a} = L_{\delta_e}/M_{\delta_e} = 0.50$. The different types of coupling were evaluated separately and in combination.

g. Thrust-Vector Control Independent of Aircraft Attitude

Independent thrust-vector control (ITVC) enables the pilot to maneuver aircraft having large drag parameters without large attitude changes. Also, with ITVC, large aircraft can be maneuvered near the ground with a reduced probability of tail strikes (and wing strikes, if lateral ITVC is also available). Only longitudinal ITVC was investigated in this study and it was implemented in two ways. In the first approach the longitudinal thrust vector was rotated using a thumb switch which commanded a constant rate of rotation. Pitch attitude was controlled using the conventional control stick. This technique for thrust-vector control was identical to the implementation of the wing tilt (or thrust-vector) control which was used by the evaluation pilots to trim the effects of mean wind acting through the longitudinal drag parameter. The wing tilt capability was available for all test cases evaluated in the UARL study. However, only for the ITVC study was the pilot permitted to use this device for general position control. The second method of implementation involved proportional control of the thrust-vector angle using the control stick while pitch attitude was controlled with the thumb switch. The thumb switch commanded a fixed rate-of-change of pitching moment ($\dot{M}_{TS}$). In general, the thrust-vector angle was displayed on the contact analog display with a symbol that moved vertically. Thrust-vector angle was also displayed on the instrument panel. For some of the experiments only the instrument panel display was used. Two Level 1 configurations (BC1 and BC4) and a Level 2 configuration (BC2) were used in the ITVC study. These configurations provide a range of position response characteristics with which to test ITVC. Configurations BC1 and BC2 have low drag parameters ($X_u = Y_v = -0.05$) and, consequently, low position stability and low position response to turbulence. Configuration BC4 has large drag parameters which give it greater position stability but also larger gust-induced position disturbances. Attitude control moments were unlimited for this

study and the thrust-vector angle could be rotated through ±90 deg. Pitch and roll control-moment usage and thrust-vector angle were measured in the ITVC study.

h. Rate-Command/Attitude-Hold Control

The rate-command/attitude-hold or "stick steering" control system has two significant attributes. First, it will hold trim attitudes while allowing the pilot to center the stick and, second, it provides a rate-command control response for higher frequency control motions. A representative attitude transfer function (pitch) for such a system is given by Eq. (3):

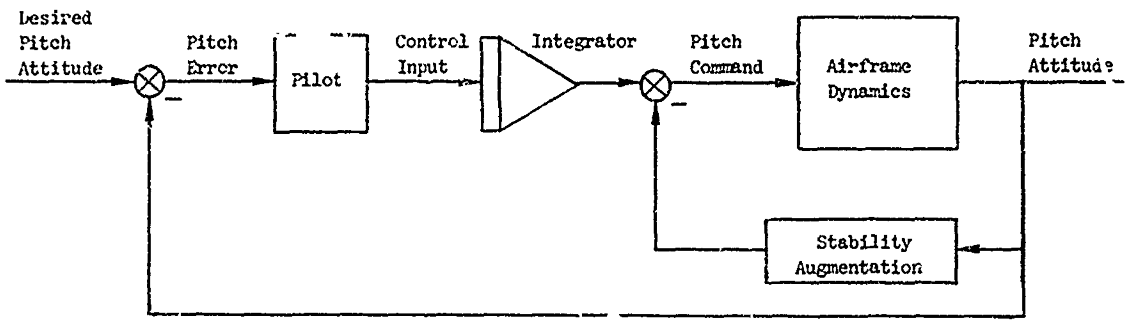
$$\frac{\theta}{\delta_e}(s) = \frac{M_{\delta_e}}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)} \tag{3}$$

This transfer function can be obtained for a rate and attitude stabilized V/STOL aircraft by integrating the control stick input to the attitude control system. This is the feature which enables the pilot to hold trim attitude with no steady-state control input. The attitude stabilization must then be increased to values which drive the real root of the attitude dynamics, i.e., the real root of the hovering cubic, towards zero, where it will be cancelled by the first-order zero related to drag parameter. If the natural frequency of the quadratic term in Eq. (3) is then sufficiently large, the transfer function θ/δ_e at and below the pilot's crossover frequency ($\omega_c \approx 2.5$ to 3.5 rad/sec, Ref. 8) will effectively be

$$\frac{\theta}{\delta_e}(s) \approx M_{\delta_e}/s \tag{4}$$

However, the dynamics still retain the attitude stabilization features. The lead compensation that must be supplied by the pilot for pitch and roll control and, consequently, the longitudinal flying qualities of this control system, are very dependent on the damping ratio, ζ, and natural frequency, ω_n, of the quadratic in Eq. (3). The rate-command/attitude-hold control system for pitch attitude (and also roll) was implemented as shown in Sketch II-F for this study.

For this study the basic longitudinal and lateral airframe derivatives of configurations BC1 and BC4 were used as a base and the rate damping (M_q, L_p) and attitude stabilization (M_θ, L_ϕ) parameters were varied to provide a broad range of ζ and ω_n for the pitch and roll dynamics. The initial parameters chosen were based on a closed-loop analysis of the pilot-aircraft dynamics. Values for ζ and ω_n that could not be obtained with simple



SKETCH II-F. Implementation of Rate-Command/Attitude-Hold Control

attitude and rate feedbacks were not evaluated in this study. Again, the pitch and roll attitude dynamics were identical for each test case.

2. Height Control

The height control program consisted of four studies. They were concerned with the effects on flying qualities of (1) height velocity damping, Z_W, with effectively unlimited thrust, (2) the interaction between Z_W and the installed thrust level, (3) thrust lags and delays, and (4) thrust available through stored energy. The longitudinal, lateral and directional characteristics were defined by the basic configurations and are shown in Table A-I. Pitch, roll and yaw control moments were effectively unlimited. The data obtained consisted of pilot ratings, pilot-selected collective control sensitivities and thrust usage. The measured thrust usage was made up of that which the pilot attempted to command, $Z_{\delta_C} \cdot \delta_C$, and that actually commanded, $Z_{\delta_C} \cdot \delta_C + Z_{W_S} \cdot w$, where Z_{W_S} is the height damping resulting from stability augmentation.

a. Effects of Height Velocity Damping with Unlimited Thrust

This study was undertaken primarily to provide more information on the minimum acceptable level of height velocity damping, Z_W. The MIL-F-83300 specification (paragraph 3.2.5.4) assumes that Level 1 flying qualities for height control can exist for $Z_W = 0$ provided sufficient thrust is available ($T/W > 1.10$). A previous UARL study (Ref. 7) contains data which indicate that a level of $Z_W \approx -0.5$ is necessary for satisfactory height control. A secondary objective of the study was to measure thrust usage data with effectively unlimited thrust-to-weight ratio ($T/W > 1.15$). Levels of total height damping, Z_{W_T}, ranging from 0 to -0.8 were evaluated with configurations BC1 and BC4. The total damping was assumed to consist of equal aerodynamic, Z_{W_a}, and stability augmentation system (SAS), Z_{W_S}, components.

b. Interaction Between Z_w and Installed Thrust Level

The height control power portion of MIL-F-83300 (paragraph 3.2.5.1) is based on the premise that increased height velocity damping reduces the necessary installed thrust. The study described here was conducted to provide more information on this effect. Height control was evaluated with configuration BC1 for six or more levels of Z_{w_T}, ranging from -0.1 to -0.5, at each of three installed thrust-to-weight ratios (T/W = 1.02, 1.05, 1.10). The T/W ratios considered are pertinent to the definition of level boundaries for the height control power specification. Generally Z_{w_T} was composed of equal parts of aerodynamic, Z_{w_a}, and SAS, Z_{w_s}, damping. However, the effects of all Z_{w_a} or all Z_{w_s} were also investigated.

c. Thrust Lags and Delays

This investigation was designed to test the specification for thrust magnitude control lags (paragraph 3.2.5.2). First-order lags which result in height control response that spans the Level 1 and 2 requirements (τ_h = 0.3 and 0.6) were evaluated with and without 0.1-sec delays. These lags and delays affected both the control and SAS thrust commands. Configuration BC1 was used and several values of Z_{w_T}, composed of equal Z_{w_a} and Z_{w_s} components, were simulated for each combination of control lag and delay. Also, the installed T/W was limited to 1.05 for this study.

d. Thrust Available Through Stored Energy

The effects of incremental thrust from rotor-propulsion system stored energy were investigated using configuration BC1 with height control characteristics that were unsatisfactory without stored energy ($Z_{w_T} = Z_{w_s} = -0.35$, T/W = 1.02). Two levels of incremental T/W representing momentary thrust increases of approximately 15 percent and 30 percent, i.e., $\Delta T/W = 0.13$ and 0.28, were evaluated with decay time constants of $\tau_\Delta = 0.05$, 0.1 and 0.2 sec. Stored energy was simulated as described for pitch control in Section II.A.1.e.

3. Directional Control

The three directional control studies investigated (1) the effects of damping on flying qualities and control-moment usage, (2) control lags and delays, and (3) limits on the available control moment. Two of the basic configurations (BC1 and BC2) were used to represent V/STOL longitudinal and lateral control characteristics. The height-control parameters for the directional studies were as shown in Table A-I. Pitch and roll control moments and thrust-to-weight ratio were effectively unlimited. Yaw control moments were also unlimited unless noted otherwise. Pilot ratings, pilot-selected directional control sensitivities and pitch, roll and yaw control-moment usage were recorded.

a. Effects of Yaw Rate Damping

This study was conducted to provide additional information on the relationship between yaw rate damping and flying qualities and to obtain control-moment-usage data. Yaw rate damping values which spanned the Level 1, 2 and 3 specifications (paragraph 3.2.2.2), for directional damping (N_r = -1, -0.5 and 0, respectively) were evaluated for basic configurations BC1 and BC2. For all test cases N_v was 0.005.

b. Control Lags and Delays

The effects of directional control lags and delays were also investigated to provide results with which to test the control-lag specification (paragraph 3.2.4). First-order control lags (which affected the pedal response only) with time constants τ_ψ = 0.3 and 0.6 were evaluated with and without 0.1-sec delays in control response. These lag and delay combinations were each evaluated at N_r levels of -0.5 and -1. Only configuration BC1 was used in this study and N_v remained 0.005.

c. Yaw Control-Moment Limits

The levels of yaw control moment necessary for satisfactory directional control were determined (1) to provide comparative results for the MIL-F-83300 control power requirement (paragraph 3.2.3.1) and (2) to evaluate the hypothesis that acceptable moment limits correlate with a level exceeded some small percent of the time for unlimited available moments. Configuration BC1 was again used in this study and N_v remained 0.005. The yaw control-moment limits considered were N_{c_m} = 0.10, 0.13 and 0.16 and the effects of these limits were evaluated for two values of N_r, -0.5 and -1.0. The smallest limit considered, N_{c_m} = 0.10, was based on yaw control-moment data measured in the turbulence study (Section II.A.1.b). It was the average level exceeded 5 percent of the time for the 3.4 ft/sec rms turbulence intensity.

B. Description of Simulation

1. Simulation of V/STOL Aircraft and Winds

The six-degree-of-freedom equations of motion for hovering and low-speed flight were programmed on an analog computer. They were written using a body-axis coordinate system and were linearized assuming small perturbations from hovering flight (Eq. (F-1), Appendix F; Refs. 7 and 8). Also, the angular momentum effects of such spinning masses as propellers and jet engine rotors were not considered. Products of inertia have also been assumed to be negligible and, with the exception of N_v, derivatives which couple motion between axes were generally disregarded. Pitch and roll rate coupling and control coupling were examined in one of the longitudinal and lateral control studies, however. The wind simulation consisted of a 10 kt ($\approx$17 ft/sec)

mean wind from the north (000 deg true), U_m, and turbulence which was introduced along the aircraft x and y body axes. Turbulence was simulated by passing the output of a random noise generator, which had a relatively uniform low-frequency power spectral distribution, through a first-order filter with a break frequency of 0.314 rad/sec (Refs. 7 and 8). The simulated turbulence then excited aircraft rotational and translational motion through the aircraft speed-stability and drag parameters and the yaw-due-to-lateral-velocity parameter (see Eq. (F-1), Appendix F). The turbulence intensity was always equal in the x and y axes, and, in general, an rms level of $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec was used. With this turbulence intensity, the wind simulation was the same as that used for much of the previous Norair study conducted under the VIFCS program (Ref. 9). Turbulence intensity levels of $\sigma_{u_g} = \sigma_{v_g} = 5.8$ and 8.2 ft/sec were also considered in the study of turbulence effects.

2. Flight Simulation and Display

Fixed- and moving-base VFR flight simulations were used. For any given study, the moving-base simulations were used to check selected fixed-base data which had been previously obtained. Generally, about half the test cases in a particular study were evaluated in the moving-base mode. The same flight simulator used in the previous UARL VIFCS studies (Refs. 7 and 8) was also used for this program. A motion platform has been added to the device, however (Fig. 2).

The simulator consists of a fully enclosed, two-place Sikorsky S-61 cockpit with a conventional instrument panel, a contact analog display for VFR flight simulation, and the six-degree-of-freedom motion platform. The control system for this simulation was made up of standard helicopter flight controls plus a thumb-switch device which could be used to change the longitudinal thrust-vector angle (or wing-tilt angle) and thereby trim the effects of the mean wind acting through the longitudinal drag parameter. The display (Fig. 3) is composed of a ground grid, horizon line, clouded sky and display symbols. Attitude and coarse position information are obtained from the motion of the ground grid, horizon and sky relative to a cross symbol which represents the nose of the aircraft. The cross may either be the electronic symbol shown in Fig. 3 or simply a marker physically attached to the screen surface. For the independent thrust-vector control and height control studies, the latter method was used and the electronic cross was moved to the right side of the screen to indicate thrust-vector angle and altitude, respectively. Precise aircraft position and velocity information are obtained from the motion of the square symbol which indicates a spot on the ground. At the reference hovering altitude of 40 ft, the dimensions of the contact analog screen represented a hover pad approximately 130 ft (longitudinally) by 150 ft and the square symbol an area about 9 ft on a side.

Simulator motion is provided by coordinated movement of the six hydraulic actuators on which the cockpit is mounted (Fig. 2). The stroke position of each actuator, commanded in response to the simulation equations of motion, is generally computed using hard-wired analog circuitry. A PDP-8 digital computer is used to set control modes of the motion platform and to monitor system performance. The simulator motion capabilities are summarized in Table II. The amplitude of the motion-platform frequency response is flat to beyond 1 Hz for each type of angular (e.g., pitch, roll or yaw) or linear motion. The phase lag for each type of motion is approximately 30 deg at 1 Hz.

TABLE II

FLIGHT SIMULATOR ANGULAR AND LINEAR MOTION LIMITS

Axis	Angular Motion			Axis	Linear Motion		
	Attitude, deg	Rate, rad/sec	Acceleration, rad/sec^2		Position, ft	Velocity, ft/sec	Acceleration, g's
Pitch	±45	±1	±1	Longitudinal	±5	±6	±0.5
Roll	±30	±1	±1	Lateral	±5	±6	±0.5
Yaw	±45	±1	±1	Vertical	±2.5	±6	±1.0

The platform's motion limits are too small to permit duplication of all low-frequency aircraft motion commanded by the pilot, especially the linear displacements. Consequently, a "washout" logic has been developed to selectively attenuate motion commands which would cause the simulator to exceed its limits (Appendix F; Ref. 11). This system is based on measured frequency response characteristics of the human's vestibular system. It also orients the cockpit relative to the earth's gravity field to simulate low-frequency aircraft linear accelerations which otherwise could not be represented. Several pilots have evaluated the motion system with this washout logic for hovering and low-speed flight and have generally found that it provides a realistic representation of actual flight.

3. Simulated Flight Task

The flight task performed during the longitudinal and lateral and the directional control studies consisted of the following subtasks: vertical

takeoff and climb to a 40-ft hovering altitude, low-speed maneuvers (air taxi; MAN, XM, YM), quick stops (QS, XQS, YQS), turns-over-a-spot (TU), hover (HOV), and landing. The air-taxi maneuvers were conducted in both longitudinal and lateral directions through simulated distances of ±65 ft and ± 75 ft, respectively. The pilots followed a cross pattern while holding heading constant (at 000 deg true) and hovered momentarily at the cardinal points of the cross. Airspeeds were generally less than 20 ft/sec during the maneuver task. The pilots next performed the longitudinal and lateral quick stops while also holding heading at 000 deg true. Airspeeds were somewhat larger for the quick stops, and, of course, the aircraft's velocities were arrested more abruptly than for the air-taxi maneuvers. The pilots next performed ±180 deg turns while maintaining hover position and this was followed by a 60-sec precision hover at the center of the simulated hover pad. The pilots then landed the aircraft.

The turn-over-a-spot subtask was deleted for the height control study and a landing sequence (LS) subtask was performed after the hover. The landing sequence consisted of relatively rapid changes in hovering altitude from 40 ft to 20 ft and back to 40 ft. This was followed by a vertical landing.

4. Pilots

The two UARL evaluation pilots were the same pilots A and B who participated in the previous VIFCS studies conducted at UARL (Refs. 7 and 8). Both are licensed private pilots who have flown a variety of fixed-wing aircraft and one has had limited helicopter experience. They also have each accumulated several hundred hours evaluation time on the flight simulator. For each study in this program pilot B generally evaluated all the fixed-base test cases and pilot A approximately half of them. These ratios were reversed for the height control studies, however. Only pilot B performed moving-base evaluations.

Two Calspan test pilots also participated at different times in the UARL program. Each has extensive experience in both helicopters and V/STOL aircraft. Eleven moving-base simulator shifts of at least 4 hours duration each were set aside for Calspan use. Results from the Calspan evaluations are shown only for Calspan pilot B in this report.

5. Comparative Results from UARL and Norair Simulations

The UARL flight simulation was designed to correspond with that used by Norair in their previous VIFCS program (Ref. 9) and thereby provide comparable results. An indication of the success of this effort can be obtained by comparing pilot ratings for similar test cases from the two simulations. Comparable longitudinal and lateral control rating data for the six UARL basic configurations are shown in Fig. 4 and Table III. The UARL fixed-base

TABLE III

COMPARISON OF PILOT RATINGS FROM NORAIR AND CURRENT UARL STUDY

Wind Simulation: U_m = 10 kts, $\sigma_{u_g} = \sigma_{v_g}$ = 3.4 ft/sec for Both Simulations

Basic Conf.	Simulation - Case	Longitudinal Stability Derivatives				Lateral Stability Derivatives				PR	
		$M_u g$	X_u	M_q	M_θ	$L_v g$	Y_v	L_p	L_ϕ	FB	MB
BC1	UARL T1	0.33	-0.05	-1.7	-4.2	-0.33	-0.05	-1.7	-4.2	2	2
	NORAIR 308	0.33	-0.05	-1.7	-4.2	-0.33	-0.05	-1.7	-4.2		3.2
BC2	UARL T10	1.0	-0.05	-1.1	-2.5	-1.0	-0.05	-1.1	-2.5	4.5	5
	NORAIR 102	1.0	-0.05	-1.1	-2.5	-0.16	-0.10	-5.0	0		4.5
BC3	UARL T16	1.0	-0.05	-2.0	0	-1.0	-0.05	-2.0	0	5	6
	NORAIR 117	1.0	-0.05	-2.0	0	-0.16	-0.10	-5.0	0		5
BC4	UARL T7	1.0	-0.20	-3.0	-1.7	-1.0	-0.20	-3.0	-1.7	3.5	3
	NORAIR 147	1.0	-0.20	-3.0	-1.7	-0.16	-0.10	-5.0	0		4
BC5	UARL T4	0.33	-0.20	-1.7	-4.2	-0.33	-0.20	-1.7	-4.2	3.5	2
	NORAIR 334	0.33	-0.20	-2.1	-3.8	-0.33	-0.20	-2.1	-3.8		3
BC6	UARL T13	1.0	-0.20	-1.1	-2.5	-1.0	-0.20	-1.1	-2.5	4.75	6
	NORAIR 141	1.0	-0.20	-1.4	-1.7	-0.16	-0.10	-5.0	0		6.2

data are averaged over two pilots and the moving-base results are for pilot B only. The Norair ratings for each case have been averaged over several pilots. In general, the ratings from the two programs agree relatively well, generally differing by only about one unit or less. Note, however, that only for configuration BC1 were the Norair and UARL test cases completely identical. The comparable longitudinal stability derivatives were always quite similar but the lateral derivatives were generally not.

C. Data Analysis

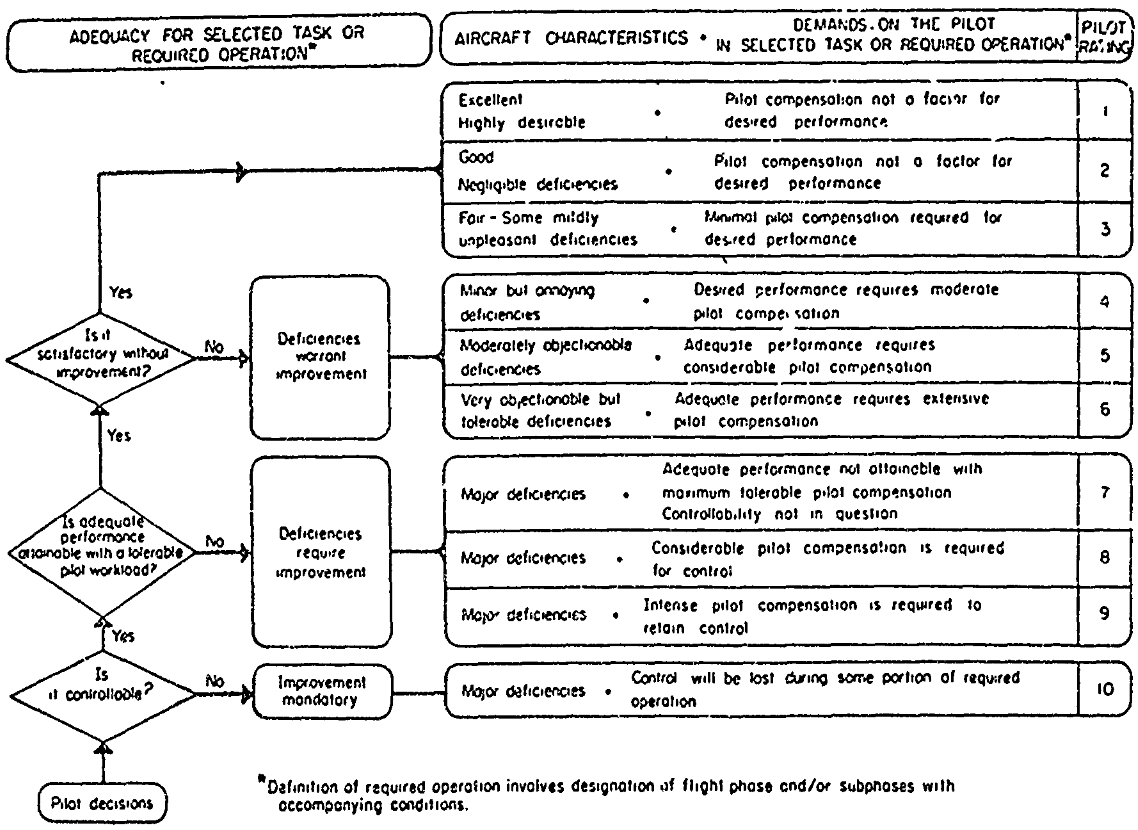
1. Reduction of Experimental Data

a. Flying Qualities Results

Pilot ratings and comments were obtained for each test case. Corresponding pilot-selected control sensitivities were also recorded. For some of the test cases, however, control sensitivities were preset at acceptable levels to save time. The pilot ratings were based on the Cooper-Harper scale (Table IV) and the pilots' comments consisted of responses to the appropriate parts of the questionnaire shown in Table V. The rating scale and questionnaire are very similar to those used in the Norair VIFCS program (Ref. 9). For presentation in the figures the UARL fixed-base rating data and control sensitivity results were each averaged over pilots A and B. The corresponding moving-base data from pilot B are shown separately. Also, Calspan pilot evaluation results were never averaged with the UARL data. Except for height and directional control, the Calspan pilots did not reach the level of control proficiency on the UAC simulator which is necessary to provide valid flying qualities data. This should not be interpreted as a reflection on the capabilities of the Calspan evaluation pilots who were both highly skilled in the control of V/STOL aircraft. Rather, the inability to become proficient, in the somewhat limited time available for Calspan pilot training, was a result of the complex nature of the UAC contact analog display (Fig. 3). This display does not provide a great deal of visual realism and in order to control properly one must rely on the relative motion between the cross and square symbols. The Calspan pilots did not learn to "lead" their control inputs properly using this relative motion information. They also tended to make control inputs of the wrong polarity, because it was difficult for them to determine the proper correlation between the symbol relative motion and the required control input. Valid flying qualities data can be obtained with the UAC display, however, for evaluation pilots who are familiar with its characteristics (e.g., Refs. 7, 8, and 12). For such pilots, the UAC display can provide visual cues (except for peripheral information) which are similar to those in actual VFR flight, and in some aspects possibly better than VFR cues (Ref. 7).

TABLE IV

COOPER-HARPER PILOT RATING SCALE



All the rating and control sensitivity data for the UARL pilots are summarized in Appendix A and the corresponding pilot comments are contained in Appendix B. Similar results from Calspan pilot B are presented in Appendix D.

b. Control Power Data

The total pitch, M_c, roll, L_c, and yaw, N_c, control moments (pilot control inputs plus that from the rate damping and attitude stabilization derivatives, i.e., the stability augmentation system commands) were measured for each test case in the longitudinal and lateral control and the directional control investigations. Pitch control moment and thrust-usage data were measured during the height control study. A representative schematic showing the point at which the pitch control-moment-usage data were measured

TABLE V

UARL FLYING QUALITIES QUESTIONNAIRE

I. Comment on selection of control sensitivities.

II. Comment on the following flying qualities areas.

A. Air-taxi-around-the-square.

1. Response to control inputs (all axes).
2. Ability to initiate motion (each direction).
3. Ability to stabilize and hold desired velocities.
4. Ability to stop precisely and come to hover at corners.
5. Are excessive attitude changes (pitch and roll) required?
6. Ability to hold heading, altitude.
7. Control deflections, trim.

B. Quick stops.

1. Can you stop as quickly as you would like?
2. Are excessive attitude changes required?
3. Ability to hold heading and altitude.
4. Control motions required.

C. Turn-over-a-spot.

1. Ability to remain over spot.
2. Attitude control (pitch and roll), height control.
3. Ability to initiate and hold turn rate.
4. Ability to stop on preselected heading.
5. Comment on use of wing-tilt control.

D. Precision hover and vertical landing.

1. Ability to establish and maintain precision hover.
   a. Attitude and angular rates.
   b. Position.
2. Adequate for vertical landing?
3. Control activity.

E. Secondary dynamics.

1. Did dynamics for one axis affect your control of another axis?

III. Overall evaluation.

A. Objectionable features.

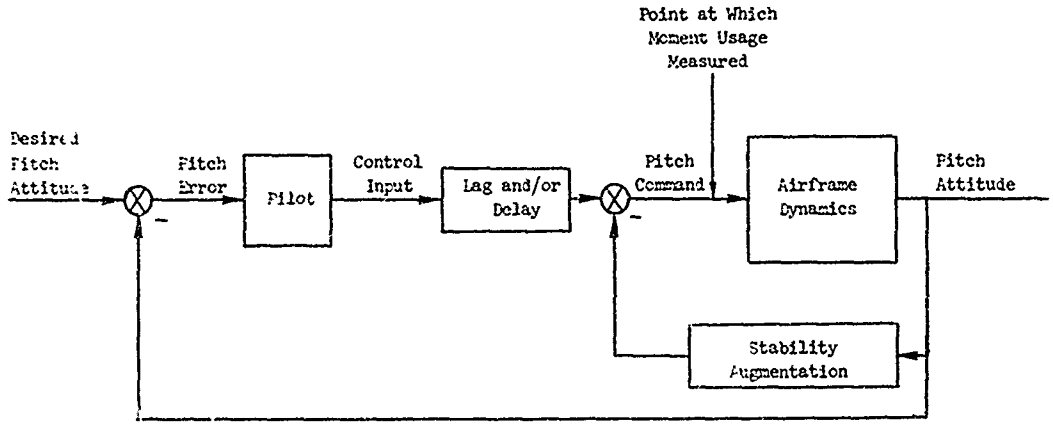
B. Favorable features.

C. Special piloting techniques.

D. Pilot rating; why?

IMPORTANT: PLEASE AVOID ALL REFERENCE AND COMPARISONS TO ANY OTHER FLIGHT. MAKE EACH SET OF COMMENTS INDEPENDENT OF ANY OTHER.

is shown in Sketch II-G. Control moment for roll and yaw control and thrust usage for height control were measured at corresponding points in the appropriate control loop. These control power data were recorded on an FM tape



SKETCH II-G. Representative (Pitch) Aircraft Control Loop Showing Point at Which Control-Moment Usage was Measured

recorder. Control power usage for the experiments in which effectively unlimited control power was available was characterized by the percent time given moment levels were exceeded for a particular subtask. For those investigations in which control power was limited, the percent time that total control power commands exceeded these limits was of interest. The exceedance percentages were computed off-line from the recorded control power data using an analog computer. Exceedance computations were performed on the magnitudes of the pitch, roll and yaw control moment data; $|M_c|$, $|L_c|$, $|N_c|$, respectively, and the combined pitch and roll moment results, $|M_c| + |L_c|$, from the longitudinal and lateral studies and from the directional control investigations. As indicated by the relationship ($|M_c| + |L_c|$) the exceedance percentages for the combined pitch and roll signal were performed on the sum of the magnitudes of total pitch and roll control moments. For the height control data, the exceedance computations were performed on $|M_c|$ and on the negative or "up" collective part of $Z_{\delta_c} \cdot \delta_c$ and $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$. It was felt that exceedance percentages computed from the thrust used to ascend or arrest sink rates would be more significant than percentages based on both positive and negative thrust usage about the trim level (T/W = 1.0).

Representative plots of exceedance results are shown in Fig. 5. There the percent time that $|M_c|$, $|L_c|$ and $|M_c| + |L_c|$ exceed the given reference levels are shown with subtask as a parameter. These data are for one pilot and are plotted on a probability grid. For the type of plots in Fig. 5, a

straight line indicates that the data can be characterized by a Gaussian probability distribution. There is some tendency for the curves from the hover and turn subtasks to exhibit this characteristic.

To simplify the task of evaluating the effects of a variety of aircraft and task parameter changes on control power usage, the control power level exceeded 5 percent of the time was chosen for comparison. The 5-percent level was selected because it is generally near the upper limit of control power used by the pilot and would presumably be related to the required installed power. A previous UARL study showed some evidence to support this assumption (Ref. 13). On the other hand, it is not such a small percentile that it would be an unreliable indicator of overall control power usage. The data in Fig. 5, for example, indicate that if the 5-percent level is used to rank the subtasks as to control-moment usage, the results are consistent with the trends evident over all percentiles. However, the 5-percent level should be more sensitive to parameter changes than larger percentile levels.

The 5-percent level results presented in this report were averaged over the two pilots participating in the study and over both moving- and fixed-base data to provide the largest possible data sample for a given test point. Averaging the moving- and fixed-base data appeared to be valid since the differences in these two types of data were less than the inter-pilot variation. That is, there was generally no dramatic difference between fixed- and moving-base data. Representative results which support this conclusion are shown in Fig. 6.

2. Analytical Investigations to Interpret the Data

Two types of analytical efforts were undertaken to interpret and rationalize the experimental results. One involved converting the parameters in MIL-F-83300 which specify satisfactory V/STOL response into functions which could readily be compared with the UARL flying qualities and control power data. The computations were performed to permit evaluation of the MIL-F-83300 requirements for control sensitivities, control power and satisfactory levels of control lags and delays.

The second type of analytical investigation was man-machine analysis of the different control loops (longitudinal, lateral, height and directional) closed by the pilot when controlling a V/STOL aircraft. The results of these analyses were used to select parameters to be considered in the experimental studies and to interpret pilot opinion data in terms of the pilot lead and gain compensation required. The closed-loop models and analytical techniques used here are discussed in detail in previous UARL reports (e.g., Refs. 7, 8 and 14).

SECTION III

RESULTS OF LONGITUDINAL AND LATERAL CONTROL STUDIES

This section consists of two parts in which the results of the longitudinal and lateral control studies are discussed. Part A is concerned with flying qualities data and Part B with control-moment usage data. Details of the experimental design, the equipment and procedures and other background material are given in Section II.

A. Flying Qualities Results

Pilot ratings and pilot-selected control sensitivities from the studies of (1) turbulence, (2) control lags and delays, (3) control moment limits, (4) control moments through stored energy, (5) inter-axis motion coupling, (6) thrust-vector control independent of attitude, and (7) rate-command/attitude-hold control are discussed here. The data are interpreted using man-machine analysis methods and, where appropriate, are compared with MIL-F-83300.

1. Turbulence

a. Pilot Ratings

The flying qualities of the six basic configurations were each evaluated at three turbulence intensities ($\sigma_{u_g} = \sigma_{v_g}$ = 3.4, 5.8 and 8.2 ft/sec) to determine the sensitivity of representative Level 1, 2 and 3 V/STOL aircraft to changes in turbulence intensity. Pilot ratings from these evaluations (Cases T1 through T18, Table A-II) are presented in Fig. 7. The pilots were not aware of the turbulence intensity level present for a given test case. As might be expected, the ratings generally deteriorated as gust intensity increased. However, it appears that the rate of deterioration may have been greater for configurations with the less stable (Levels 2 and 3) dynamics. For example, there was no degradation in ratings for the Level 1 configurations as rms turbulence intensity was increased from 3.4 to 5.8 ft/sec. A general increase in rating for the Level 1 configurations is evident, however, at the 8.2-ft/sec intensity, although the ratings all remain in the acceptable region (Fig. 7(a)). A much more definite deterioration in ratings is evident for the Level 2 and 3 configurations, especially for the change in turbulence intensity from 3.4 to 5.8 ft/sec.

The degradation in rating is shown more clearly in Fig. 8 where it is plotted versus configuration flying qualities level, with the change in turbulence intensity treated as a parameter. The degradation in fixed-base ratings for Level 2 and 3 configurations is much greater than that for Level 1 configurations over the turbulence intensity interval 3.4 to 5.8 ft/sec. Except for

BC4, which is Level 1 but relatively responsive to gusts, this trend is also evident (to a lesser extent) for the intensity interval 3.4 to 8.2 ft/sec. There is not sufficient moving base data to permit a complete comparison between levels. However, over the turbulence interval 3.4 to 8.2 ft/sec, the degradation in moving-base ratings for Level 1 configurations BC1 and BC4 is less than the corresponding fixed-base degradation. The moving-base degradation for BC5 is greater than its fixed-base counterpart but still smaller than the fixed-base degradation for the Level 2 and 3 configurations. In summary, the pilot rating data would tend to indicate (but by no means confirm) that the MIL-F-83300 Level 1 requirement for V/STOL pitch, roll and yaw dynamic response (paragraph 3.2.2) provides aircraft dynamics which remain quite controllable for nominal increases in turbulence intensity.

The rating data can be interpreted by considering the aircraft attitude and position response to turbulence and the phase lags of the attitude dynamics at frequencies critical to pilot control. It has been shown (Refs. 7 and 8) that pilot rating is related to both the workload involved in suppressing turbulence and the lead compensation he must supply to provide good closed-loop attitude characteristics. This lead compensation is inversely dependent on the attitude phase lags over the frequency interval from about 1 to 4 rad/sec (Refs. 7 and 14). The frequency domain characteristics of the open-loop attitude and position response to turbulence for the six basic configurations are shown in Figs. 9 and 10. The phase lags contributed by the pilot and the open-loop attitude dynamics for these configurations are presented in Fig. 11. The pilot's lags are assumed to consist of a pure delay of 0.09 sec in combination with a first-order lag having a 0.2-sec time constant (Refs. 7 and 14). An examination of the phase lag and turbulence response curves will indicate why the Level 1 configurations BC1 and BC5, and to a lesser extent, BC4, have generally better flying qualities and are less affected by turbulence than the Level 2 and 3 configurations. The phase lags (Fig. 11) for BC1, BC4 and BC5 are all appreciably smaller than those for the Level 2 and 3 configurations over the critical frequencies (ω = 1.5 to 4 rad/sec, Fig. 11). This indicates that the pilot need supply less lead compensation to provide good attitude control characteristics. Also, the normalized open-loop attitude and position power spectral densities for BC1 and BC5 are appreciably smaller than those for the Level 2 and 3 configurations. The power spectral densities for BC4, the remaining Level 1 configuration, are comparable to those for BC2, BC3 and BC6 over the lower frequencies but are smaller at the higher frequencies which are more difficult for the pilot to suppress. Consequently, the opinion ratings for BC4 might be expected to exhibit a somewhat smaller sensitivity to gust intensity than BC2, BC3 and BC6.

b. Control Sensitivities

Longitudinal and lateral control sensitivity data are shown in Figs. 12 and 13, respectively. For most of the six configurations, the longitudinal control sensitivities, M_{δ_e}, tend to increase with turbulence intensity. This trend reflects the pilot's requirement for more rapid attitude and position responses to control inputs as he tried to maintain performance in the presence of increasing gust disturbances. For some of the configurations (BC4, BC5 and BC6) the lateral control sensitivities (Fig. 13) tend to increase with turbulence intensity, but this trend is not consistent for all configurations. In fact, the control sensitivities selected for BC3 tend to decrease slightly for the larger gusts. Such inconsistencies are not unexpected, since previous studies have shown that a fairly broad range of control sensitivities are acceptable to most pilots (Refs. 7 and 9). Figures 12 and 13 also contain boundaries for the maximum and minimum control sensitivities permitted under the MIL-F-83300 specification for aircraft attitude response to control inputs (paragraph 3.2.3.2). These sensitivity boundaries were back-calculated using the attitude response specifications and the known aircraft dynamics. It is apparent from the distance between these boundaries that the specification permits appreciable latitude in the installed V/STOL pitch and roll sensitivities. The values of M_{δ_e} and L_{δ_a} selected by the UARL pilots generally fall within these boundaries, but are much closer to the minimum acceptable level than the maximum. In fact, for the Level 1 configurations (BC1, BC4 and BC5), most of the lateral control sensitivities are somewhat below the lower boundary. Larger minimum values are required by MIL-F-83300 for lateral control sensitivities than longitudinal, assuming the pitch and roll dynamics are symmetrical. In studies at UARL, however, L_{δ_a} has generally been found to be smaller than M_{δ_e} (Refs. 7 and 8).

2. Control Lags and Delays

a. Pilot Opinion Ratings

Pilot rating data from the three parts of the control lag and delay investigation are discussed in the following order: (1) first-order control lags, (2) first-order control lags in combination with a 0.1-sec delay, and (3) second-order control lags. The test cases evaluated in these studies were LL1-LL27 and results of the evaluations are summarized in Table A-III (Appendix A).

The effects of the first-order control lags on ratings are shown in Fig. 14. These lags affected only the pilot's control stick commands and not the SAS inputs. Also, the lags were identical for both pitch and roll. As might be expected, the ratings generally deteriorated as the lag time constant, $\tau_e = \tau_a$, increased. However, the sensitivity of a given configuration's flying qualities to the lag time constant appeared to correlate with

the flying qualities level (without lags) of the configuration. For example, most of the ratings for the Level 1 configurations at $\tau_e = \tau_a = 0.6$ sec were within one unit of the ratings given for no lags. The Level 2 and 3 configurations generally show a noticeable deterioration in rating at $\tau_e = \tau_a = 0.3$ sec. The degradation in rating is plotted versus flying qualities level in Fig. 15 with the change in lag time constant as a parameter. There is considerable scatter in these results, but the fixed-base data generally show that the degradation in rating was greater for the Level 2 and 3 configurations.

The Level 1 configurations should be somewhat less sensitive to control lags. The primary effect of the control lags is to introduce phase lags (Fig. 16) which increase the need for pilot lead compensation. They do not affect the aircraft response to turbulence. The Level 1 configurations require little lead compensation without lags because their open-loop phase lag is small (Fig. 11). Pilots will tolerate nominal requirements for lead compensation without a significant change in rating (Refs. 7 and 14). Consequently, the ratings for Level 1 configurations do not change appreciably until the lag time constant reaches a relatively large value (e.g., $\tau_e = \tau_a = 0.6$). However, for the Level 2 and 3 configurations the requirements for pilot compensation are at a relatively high level with no lags (Fig. 11). In this situation the pilots appear to be more sensitive to the increased lead requirements, possibly because it is more difficult to supply the needed increment. Note that the magnitude characteristics of the basic configuration-lag combination, which will not be discussed here, may also affect pilot opinion (Refs. 14 and 15).

The specifications for pitch and roll control system lags can be evaluated using the pilot rating data in Fig. 14. The specification (paragraph 3.2.4) is based on the time it takes aircraft attitude to reach the initial maximum angular acceleration, $t_{\ddot{\theta}_{max}}$ and $t_{\ddot{\phi}_{max}}$, after the initiation of the control command. If these times are less than 0.3 sec the attitude dynamics are considered satisfactory. Values of these times have been computed with $\tau_e = \tau_a = 0.1$, 0.3, and 0.6 sec for each of configurations BC1, BC4 and BC5 and they are summarized in Table VI along with the associated pilot ratings. These results show that the specification permits a $\tau_e = \tau_a = 0.3$ sec for the configurations evaluated; these cases were also generally rated satisfactory. The specification would preclude $\tau_e = \tau_a = 0.6$ sec although the fixed-base ratings remained marginally satisfactory for these cases. However, the moving-base ratings for the first-order control lag evaluation were generally worse than the fixed-base results. Consequently, it would appear that excluding control lags much greater than $\tau_e = \tau_a = 0.3$ sec, as the specification does, is prudent.

TABLE VI

COMPARISON BETWEEN PILOT OPINION RATINGS AND THE MIL-F-83300 REQUIREMENT FOR ACCEPTABLE ATTITUDE CONTROL LAGS

Basic Conf.	Lag Time Constant, $\tau_e = \tau_a$, sec	Time to Max. Acceleration, $t_{\ddot{\theta}max} = t_{\ddot{\phi}max}$, sec	Average Pilot Rating	
			Fixed Base Mode	Moving-Base Mode
BC1	0.1	0.19	2	
	0.3	0.31	2.75	
	0.6	0.38	2.5	5.5
BC4	0.1	0.15	2	3.5
	0.3	0.29	2.75	5
	0.6	0.46	3.5	
BC5	0.1	0.18	2	
	0.3	0.30	2	
	0.6	0.38	3.5	3

The effects of adding a 0.1-sec time delay in pitch and roll response for Level 1 and 2 configurations (level designation applies for no lags or delays) are shown in Table VII. Such delays also increase the requirements for pilot adapted lead compensation by increasing the phase lags in the attitude response to control inputs. However, as indicated in Fig. 16, a 0.1-sec delay contributes relatively small phase lags over the frequency range (~1 to 4 rad/sec) most critical to pilot control of attitude. Time delays greater than 0.1 sec were not considered since the specification (paragraph 3.2.4) excludes them. In this study the time delays ($d_e = d_a$) were added separately and in combination with first-order lags ($\tau_e = \tau_a$) having 0.3-sec time constants. For one of the cases (indicated by the superscript 2 in Table VII) the time delays and lags affected both the pilot's control inputs and the SAS commands. For all other cases the time delays and lags operated only on the control input. For the Level 1 configuration (BC1) the 0.1-sec time delays in the pilot's pitch and roll control inputs had little effect on pilot rating, whether or not the 0.3-sec lags were also present. For example, adding $d_e = d_a = 0.1$ sec with $\tau_e = \tau_a = 0$ did not change the pilot's rating (PR = 2 for both cases). Also, adding $d_e = d_a = 0.1$ with $\tau_e = \tau_a = 0.3$

TABLE VII

EFFECTS OF TIME DELAYS AND CONTROL SYSTEM LAGS ON PILOT RATINGS

BC1 is Level 1 and BC2 is Level 2 Without Lags and Delays

Basic Conf.	Lag Time Constant, $\tau_e = \tau_a$, sec	Time Delay $d_e = d_a$, sec	Ratings from Pilot B for Fixed-Base Mode
BC1[1]	0	0	2
	0	0.1	2
	0.3	0	2.5
	0.3	0.1	3
	0.3[2]	0.1[2]	8[2]
BC2[1]	0	0	5
	0	0.1	5
	0.3	0	5
	0.3	0.1	7

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative; pitch and roll lags and delays equal.
2. For this case the lag and delay operated on both the control input and the SAS command. For all the other cases only the control input was affected.

resulted in a pilot rating deterioration of only 0.5 units relative to the rating with only the 0.3-sec lags. However, the results in Table VII show a dramatic change in rating when the lags and delays were relocated so that they affected both the control and SAS commands (PR = 8 versus PR = 3). In this case, the stability augmentation was much less effective and, as a result, the configuration was very difficult to control. The pilot's chief complaint (Case LL25, Table B-II, Appendix B) was that large pitch oscillations developed; it was nearly impossible to damp them and stabilize pitch attitude. The results for the Level 2 configuration (BC2) also show little change when $d_e = d_a = 0.1$ were added with $\tau_e = \tau_a = 0$ sec. However, when the same delays were added to BC2 with $\tau_e \quad \tau_a = 0.3$ the associated pilot rating was two units worse than for the lags without the delays (PR = 7 versus PR = 5). Note, however, that the rating for the lags alone was somewhat better than would be expected. That is, it is the same rating (PR = 5) as was assigned to BC2 with neither lags nor delays present in the control response. The

results in Table VII, although limited, would tend to indicate that 0.1-sec delays in the pilot's pitch and roll control responses are acceptable, at least for Level 1 configurations. That is, the specification (paragraph 3.2.4) which permits delays in the pitch or roll attitude response to control inputs of up to 0.1 sec, appears to be reasonable.

Second-order lags were also evaluated during this study to provide some information on the generality of the MIL-F-83300 specification for control lags. The specification is based on the results of studies with first-order control lags; however, because it is phrased in terms of an angular acceleration response which must be achieved within a reference time interval, it may also apply to more general lags. Four sets of parameters for the second-order lag were evaluated ($\omega_{n_e} = \omega_{n_a} = 3.33$ rad/sec with $\zeta_e = \zeta_a = 0.22$, 0.50, and 1.0 and $\omega_{n_e} = \omega_{n_a} = 8.23$ with $\zeta_e = \zeta_a = 1.0$). As for the first-order lag study the lags only affected the pilot's control response and they were identical in pitch and roll. The initial combination of parameters was selected to have the same break frequency ($\omega_n = 3.33$) as that for an acceptable first-order lag ($1/\tau_e = \omega_{n_e}$ where $\tau_e = 0.3$). The damping ratio, $\zeta_e = \zeta_a$, was adjusted to give the same phase lag as that from the first-order lag in the region of the pilot's crossover frequency ($\omega_c = 2.5$ to 3 rad/sec; see Refs. 8 and 14). Consequently, the lead compensation requirements for the two lags would be similar. However, the nature of the control stick response would be quite different because of the lightly damped ($\zeta_e = \zeta_a = 0.22$) oscillations present for the second-order lag. The magnitude and phase characteristics of the open-loop pilot and attitude dynamics, without pilot lead or gain compensation, are shown in Fig. 17.

Results from the evaluation of second-order lags with configuration BC1 (Fig. 18) show that the combination of parameters ($\zeta = 0.22$, $\omega_n = 3.33$) selected for equivalence with $\tau_e = \tau_\varepsilon = 0.3$ resulted in a pilot rating of 10. Pilot comments indicated that the oscillatory pitch and roll motion was completely unacceptable. The ratings improved with increased damping ratio, but a satisfactory rating was not obtained even with $\zeta_e = \zeta_a = 1.0$. Here the oscillatory dynamics were not a problem, but lead compensation was needed to compensate the phase lags. Pilot rating was satisfactory for this damping ratio, however, with the larger natural frequency, $\omega_{n_e} = \omega_{n_a} = 8.23$ rad/sec. The attitude phase lags in the region of pilot crossover frequency (2.5 to 3.5 rad/sec) were somewhat smaller with these parameters. The pilot rating results from Fig. 18 are compared with $t\ddot{\theta}_{max} = t\ddot{\phi}_{max}$ values computed for the second-order lag test cases in the following tabulation:

$\omega_{n_e} = \omega_{n_a}$, rad/sec	$\zeta_e = \zeta_a$	$t_{\ddot{\theta}_{max}} = t_{\ddot{\phi}_{max}}$	PR
3.33	0.22	0.61	10
3.33	0.50	0.58	7
3.33	1.0	0.55	4
8.23	1.0	0.33	3

The only case rated satisfactory also had a time to maximum angular acceleration which was nearly equal (0.33 sec) to that required by the specification (0.30 sec). However, $t_{\ddot{\theta}_{max}} = t_{\ddot{\phi}_{max}}$ was almost twice the specification value (0.55 sec) at $\omega_{n_e} = \omega_{n_a} = 3.33$ rad/sec and $\zeta_e = \zeta_a = 1.0$ for a test case rated marginally satisfactory (PR = 4). These very limited results indicate, then, that the control lag specification may not be sufficiently general to apply to second-order control lags.

b. Control Sensitivities

Longitudinal and lateral control sensitivities from the investigation of first-order control lags are presented in Figs. 19 and 20, respectively. It might be expected that pilot-selected control sensitivities would increase somewhat with lag time constants since the lags result in slower attitude response. For the longitudinal sensitivities, M_{δ_e}, there is little evidence of this except possibly for configuration BC3 (Fig. 19). The lateral sensitivities, L_{δ_a}, exhibit some tendency to increase with τ_a and, again, this effect is more pronounced for BC3. Configuration BC3 is Level 3 and very difficult to control as the lags become larger. The pilots may have increased sensitivity in an attempt to more quickly attenuate the large attitude excursions which tended to develop for $\tau_e = \tau_a = 0.3$ and 0.6 sec.

Boundary values for acceptable minimum and maximum longitudinal and lateral control sensitivities developed from the MIL-F-83300 specification for attitude control response (paragraph 3.2.3.2) are shown for the Level 1 configurations in Table VIII. Both the minimum and maximum boundaries increase with $\tau_e = \tau_a$ because the specification is written in terms of an acceptable response after a given time period. Because the lags slow the attitude control response, the sensitivities must increase to satisfy the specification. For the small lag time constants the pilot-selected lateral and longitudinal sensitivities are close to the specification's lower boundaries (M_{δ_e} and L_{δ_a} are averages of fixed- and moving-base data). For the larger time constants the sensitivities fall below the minimum boundaries. Note also that the maximum sensitivity boundaries are very much larger than the UARL selected values. It may be appropriate to lower the minimum boundaries somewhat and it would seem that the maximum boundaries also could be reduced. The maximum allowable sensitivities would, in general, result in extremely "touchy" aircraft pitch and roll response to control inputs and could cause the pilot to overcontrol.

TABLE VIII

COMPARISON OF AVERAGED LONGITUDINAL AND LATERAL CONTROL SENSITIVITIES FROM THE CONTROL LAG STUDY WITH THE MIL-F-83300 REQUIREMENTS

Basic Conf.	Lag Time Constant, $\tau_e = \tau_a$, sec	UARL M_{δ_e}	MIL-F-83300 M_{δ_e} Boundaries		UARL L_{δ_a}	MIL-F-83300 L_{δ_a} Boundaries	
			Min.	Max.		Min.	Max.
BC1	0	0.291	0.233	1.560	0.271	0.312	1.560
	0.1	0.303	0.261	1.740	0.244	0.348	1.174
	0.3	0.311	0.342	2.278	0.223	0.456	2.278
	0.6	0.372	0.490	3.268	0.312	0.654	3.268
BC4	0	0.342	0.258	1.721	0.302	0.344	1.721
	0.1	0.404	0.291	1.940	0.334	0.388	1.940
	0.3	0.403	0.384	2.561	0.321	0.512	2.561
	0.6	0.412	0.552	3.683	0.384	0.737	3.683
BC5	0	0.293	0.233	1.560	0.243	0.312	1.740
	0.1	0.304	0.261	1.738	0.241	0.348	1.738
	0.3	0.283	0.343	2.288	0.220	0.458	2.288
	0.6	0.324	0.489	3.263	0.301	0.635	3.263

3. Control Moment Limits

In this study the installed control moments required for pilot acceptance were determined for several of the basic configurations (BC1, BC4, BC5 and BC6). The correlation between the requirements for control moment and the levels exceeded some given small percent of the time with unlimited moment available, i.e., the 5-percent level, was also examined. This study was performed with and without control system lags and delays. Also, the pilots were not aware of the control-moment limits except as they affected flying qualities. Results from this study are listed for Cases LM1-LM25 in Table A-IV in Appendix A.

The effects of control-moment limits on pilot rating of the flying qualities of configurations BC1, BC4, BC5 and BC6 are presented in Fig. 21. The reference limits or starting points for the installed control-moment levels (pitch, roll, and yaw) were averages of those levels exceeded 5 percent of the time ($\overline{CM}_5$) with unlimited moment available (see Section III.B.1.d). These averages were computed over all subtasks, pilots and modes of simulator operation (fixed- and moving-base). The control-moment limits for the remaining test cases were obtained by increasing (or decreasing) the reference

levels by integral multiples of 10 percent. Also, the limits were applied to the total control moment available for both control inputs and the SAS commands. Note that $\overline{CM}_5$ is different for each configuration and its magnitude scales approximately with the configuration's speed-stability parameters (see Table C-I, Appendix C).

Only for configuration BC5 did control-moment limits equal to the average 5-percent exceedance level, $\overline{CM}_5$, result in ratings equivalent to those of unlimited moments (Fig. 21). Configuration BC5 is a very stable, Level 1 configuration with little response to turbulence. For configuration BC1, which is identical to BC5 except that its drag parameters are one-fourth as large, control moment limits at least 1.2 times the reference $\overline{CM}_5$ level were needed to obtain ratings equivalent to those for unlimited moments. For the configurations which were more responsive to turbulence (BC4) or both less stable and more response to turbulence (BC6), control-moment limits of 1.3 times the $\overline{CM}_5$ levels were required for equivalent ratings. For all the configurations examined, a deficiency in control moment was most evident as a momentary inability to control pitch, and to a lesser extent roll, when performing the maneuver and quick-stop subtasks. Pilot comments indicated that the limits on yaw control moment did not affect flying qualities.

Table IX contains a comparison between the control-moment limits found to be necessary for pilot acceptance in this study and the control-moment

TABLE IX

COMPARISON OF UARL ACCEPTABLE CONTROL-MOMENT LIMITS WITH MIL-F-83300 REQUIREMENTS

Conf.	Control Moment Source	Installed Control Moment, rad/sec^2		
		Pitch, M_{c_m}	Roll, L_{c_m}	Yaw, N_{c_m}
BC1	UARL MIL-F-83300	0.40 0.57	0.46 0.47	0.13 0.31
BC4	UARL MIL-F-83300	1.07 1.26	0.79 0.81	0.23 0.31
BC5	UARL MIL-F-83300	0.38 0.57	0.36 0.48	0.15 0.31
BC6	UARL MIL-F-83300	1.16 1.18	0.98 0.71	0.22 0.31

requirements in MIL-F-83300. The control moment specification (paragraph 3.2.3.1) stipulates that sufficient control moment must remain at the maneuvering airspeed to simultaneously produce aircraft pitch, roll, and yaw attitude changes of ± 3 deg, ± 4 deg, and ± 6 deg, respectively, within one second. The specification values shown in Table IX were computed assuming longitudinal and lateral maneuvering speeds equivalent to those used in the UARL task (≈ 15 ft/sec). Combining these airspeeds with the mean wind increases the effective longitudinal airspeed to ≈ 32 ft/sec. For the UARL simulation, then, the aircraft must have sufficient pitching moment, M_{c_m}, to trim the 32-ft/sec airspeed and also to provide the ± 3 deg pitch change within one second. The roll, L_{c_m}, and yaw, N_{c_m}, moments need only be sufficient to trim the 15-ft/sec lateral airspeed and provide the required attitude changes (± 4 deg and ± 6 deg, respectively).

The results in Table IX show that for all the Level 1 configurations (BC1, BC4, BC5) the pitch and roll control-moment requirements from MIL-F-83300 equalled or exceeded those found to be necessary in the UARL study. For BC6, a Level 2 configuration which is quite responsive to gusts, the specification value for L_{c_m} was about 20 percent low. However, the UARL level for M_{c_m} agrees well with the corresponding MIL-F-83300 value. Also, all of the specification levels for N_{c_m} were well in excess of the UARL results. It would appear from these relatively limited data that the MIL-F-83300 requirement for pitch and roll control moments is adequate. However, the yaw control-moment requirement seems somewhat excessive. Pilots never noticed a deficiency in yaw control moments during the UARL study even for levels of N_{c_m} considerably lower than the UARL data shown in Table IX. Limitations on pitch and roll control moment were predominant in the formation of rating. The MIL-F-83300 yaw control-moment requirement is discussed in more detail in Section V.A.3.

It was pointed out previously that another objective of this study was to determine whether the required levels for installed control moments correlated with the percent time given pitch and roll moment levels were exceeded with unlimited moments available. In particular it was thought that the 5-percent exceedance level might be sufficient. The results in Fig. 21 do not appear to substantiate such an hypothesis. However, it may be that the maximum of the 5-percent exceedance levels measured for the different subtasks should have been used for $\overline{CM_5}$ instead of the average over all subtasks. These maximum values, averaged over both pilots and fixed- and moving-base simulator modes (Table C-I, Appendix C), are listed in Table X along with the pitch and roll moment levels necessary for pilot ratings approximately equivalent to those for unlimited control moment (Fig. 21).

TABLE X

COMPARISON OF MAXIMUM FIVE-PERCENT EXCEEDANCE MOMENT LEVELS USED FOR ANY SUBTASK WITH ACCEPTABLE LIMITS ON INSTALLED ROLL AND PITCH CONTROL MOMENTS

Basic Conf.	Control Moment	Maximum 5-Percent Level	Acceptable Moment Level
BC1	M_c	0.34	0.43
	L_c	0.45	0.50
BC5	M_c	0.45	0.38
	L_c	0.50	0.36
BC4	M_c	0.90	1.07
	L_c	0.62	0.78
BC6	M_c	0.93	1.16
	L_c	0.94	0.98

The results in Table X show that only for configuration BC5 were the maximum 5-percent exceedance moment levels equal to or greater than those levels which were acceptable to the pilot. It appears, then, that the 5-percent exceedance level, whether it is composed of the average over all subtasks or the maximum for any subtask, does not provide acceptable levels of installed control moment. If configuration BC5 is considered an anomaly, the fact that control-moment levels of 1.2 to 1.3 times $\overline{CM}_5$ were acceptable may imply that a lower-percentile exceedance level, e.g., the 1 to 2 percent level, would provide acceptable installed control moments. Results related to this possibility are discussed in Section III.B.2.

The control-moment requirements with control system first-order lags ($\tau_e = \tau_a = 0.3$ and 0.6) and delays ($d_e = d_a = 0.1$ for all test cases) were also evaluated in this study for configurations BC1 and BC5. The procedures used and moment levels considered were identical to those for the evaluation of control-moment limits without lags. The effects of the control lags can be seen in Fig. 22. The necessary control-moment levels were increased by

the control lags and delay. For example, control-moment levels for BC1 equal to 1.4 $\overline{CM}_5$ were required with $\tau_e = \tau_a = 0.3$ and 0.6 and $d_e = d_a = 0.1$ for ratings equivalent to those with unlimited control moments. Control moments equal to only 1.2 $\overline{CM}_5$ were sufficient for BC1 without lags and delay (Fig. 21). For configuration BC5, 1.2 $\overline{CM}_5$ was required with $\tau_e = \tau_a = 0.6$ and $d_e = d_a = 0.1$. Without the lags and delays the corresponding required moment levels were equal to 1.0 $\overline{CM}_5$. The control-moment specification (paragraph 3.2.3.1) will account for the additional control moments required with control system lags and delays. It is stated in terms of minimum attitude responses within a certain time and, consequently, requires more installed control moments when control lags or delays are present. It should be noted, however, that the control moments required by MIL-F-83300 for no lags are generally equal to or greater than the UARL levels necessary with lags and delays. This is illustrated in the following list.

Basic Conf.	MIL-F-83300 Without Lags			UARL Acceptable With Lags		
	M_{c_m}	L_{c_m}	N_{c_m}	M_{c_m}	L_{c_m}	N_{c_m}
BC1	0.57	0.47	0.31	0.47	0.54	0.16
BC5	0.57	0.48	0.31	0.46	0.44	0.18

Only L_{c_m} for configuration BC1 from the UARL study is slightly greater than its MIL-F-83300 counterpart. If the control moment specification for L_{c_m} is computed with $\tau_a = 0.3$ under the airspeed conditions discussed previously, the MIL-F-83300 requirement for L_{c_m} becomes 0.62 rad/sec^2, an increase of about 35 percent. If the 0.1 sec delay was also considered the percentage increase would be even greater. For $\tau_a = 0.6$ the corresponding level for L_{c_m} is 0.81. In fact, the specification control moment requirement for control systems with acceptable lags may be excessive. For example, a control lag of 0.3 sec is permissible under MIL-F-83300 for both configurations BC1 and BC5. However, such a lag will increase the specification control moment requirements by approximately 35 percent to levels which are much greater than those the UARL results would indicate are necessary.

4. Incremental Control Moment Through Stored Energy

For this study the pilot could command a pitch control moment (stored energy effects were not simulated for roll) greater than the installed or continuously available total moment. It was assumed that this additional moment was provided by converting angular momentum from a rotor-propulsion

system into an increment which decayed with time (as the angular momentum was dissipated). A more detailed discussion of this effect and a description of the simulation procedures used are given in Section II.B.1.e. Representative values for the present increment and the rpm decay (and recovery) time, determined from an analysis of XC-142 propulsion system data are $\Delta M_c = 0.3\ M_{c_m}$ and $\tau_\Delta = 0.05$ to 0.10 sec. Values for τ_Δ of 0.2 may be possible for helicopters. Cases LS1-LS3 were evaluated for the stored energy investigation and flying qualities results are summarized in Table A-V in Appendix A.

The results in Fig. 23 were obtained using values for M_{c_m} which resulted in flying qualities that were significantly worse than those for unlimited control moments. The effects of stored energy were then evaluated for different combinations of ΔM_c and τ_Δ. Data are presented for basic configurations BC1, BC4, BC5 and BC6 (M_{c_m} was different for each). Some general improvement in opinion is evident in Fig. 23 for $\Delta M_c = 0.30\ M_{c_m}$ and $\tau_\Delta =$ 0.10. Definite improvement is evident for all configurations with $\tau_\Delta = 0.20$, although the ratings are poorer than for unlimited pitch control moment. Note that for $\Delta M_c = 0.50\ M_{c_m}$ and $\tau_\Delta = 0.20$ the flying qualities of BC1 are rated equal to those for unlimited pitch control moment.

Time histories of M_c, the total pitch control moment, which show the effects of stored energy are presented in Fig. 24. These results were measured for the maneuvering subtask with configuration BC1 and $M_{c_m} = 0.36$. The stored energy parameters considered are $\Delta M_c = 0.3\ M_{c_m}$ (0.11 rad/sec^2) with $\tau_\Delta = 0.1$ and 0.2 sec and $\Delta M_c = 0.5\ M_{c_m}$ (0.18 rad/sec^2) with $\tau_\Delta = 0.2$ sec. These are the parameters used with BC1 to provide the pilot ratings shown in Fig. 23. The stored energy contribution is evident in Fig. 24 as a peak which decays relatively quickly to the M_{c_m} level. Note that there is a reduction in the amount of time that the control moment is limited as the contribution from stored energy is increased.

5. Inter-Axis Motion Coupling

a. Pilot Ratings

Attitude rate coupling (M_p, L_q) and control coupling (M_{δ_a}, L_{δ_e}) were evaluated to determine acceptable limits for such effects (Cases LC1-LC8, Table A-VI, Appendix A). A related objective was to determine whether changes to MIL-F-83300 are needed to account for motion coupling. Background information on this study is contained in Section II.B.1.f. Results from the evaluation of motion coupling are shown in Fig. 25. Pilot ratings and control sensitivities are plotted there versus the level of rate coupling with control coupling shown as a parameter. Configurations BC1 and BC2 were evaluated. For most of the results the coupling effects were additive. For example, a positive pitch control input yields a positive pitch rate and since both L_q and L_{δ_e} were negative, the induced rolling moment was also

negative. For one test case coefficients having signs which resulted in cancelling moments ($L_q < 0$, $L_{\delta e} > 0$ and $M_p > 0$, $M_{\delta a} < 0$) were also evaluated. Note that the pitch and roll rate coupling levels were always equal as were the values for longitudinal and lateral control coupling.

Pilot rating showed a significant, consistent deterioration with rate coupling (Fig. 25(a)). There were no threshold effects evident in pilot rating as control coupling was changed from zero to $M_p = -L_q = 2$. That is, this level of coupling brought about a deterioration in rating of 2 units and the trend continued as rate coupling was increased. Without rate coupling, control coupling ratios up to $M_{\delta a}/L_{\delta a} = -L_{\delta e}/M_{\delta e} = 0.5$ brought about only a 1 unit decrement in rating (a value of 0.5 indicates a large amount of control coupling). As rate coupling was added the increase in rating (deterioration) caused by control coupling also became somewhat larger. It appears from Fig. 25(a) that a control coupling ratio of 0.25 could be expected to produce a 0.5 to 1 unit deterioration in rating while a ratio of 0.5 results in a 1 to 1.5 unit increase. The deterioration in rating for configuration BC2 caused by $M_p = -L_q = 2$ and $M_{\delta a}/L_{\delta a} = -L_{\delta e}/M_{\delta e} = 0.25$ was equivalent to that for BC1 with the same coupling parameters. Also, no change in rating occurred for BC2 when the signs of $M_{\delta a}$ and $L_{\delta e}$ were changed such that the rate and control coupling compensated somewhat for each other.

Attitude rate coupling appeared to have a greater effect on rating than control coupling for the levels considered in this study. The results in Fig. 25(a) would tend to indicate that MIL-F-83300 should restrict rate coupling to magnitudes less than about 1 per sec. Also, control coupling ratios greater than about 0.25 should not be permitted.

b. Control Sensitivities

Both the longitudinal and lateral control sensitivities generally tended to increase with rate coupling (Figs. 25(b) and 25(c)). The pilots apparently felt they needed a more rapid attitude response to control the coupling motion. Also, the control sensitivities for the 0.5 control coupling ratio were slightly larger than those for no control coupling. However, as indicated by the MIL-F-83300 reference lines (Fig. 25(b)), the longitudinal control sensitivities for BC1 are within the specification (the maximum boundary is well above the limits of the plot's ordinate scale). Also, the minimum boundary for BC2 is even lower than that for BC1 (not shown). The lateral BC1 sensitivities (Fig. 25(c)) for low rate coupling are somewhat lower than the minimum boundaries. However, the pilots would have had no difficulty controlling with sensitivities corresponding to the specification minimums. The effect of rate and control coupling on control sensitivities is not specifically accounted for by the MIL-F-83300 paragraph on response to control inputs (paragraph 3.2.3.2). However, the range of sensitivities permitted by MIL-F-83300 is sufficiently large that the increase in $M_{\delta e}$ and $L_{\delta a}$ caused by control coupling does not result in their exceeding the upper boundary.

6. Independent Thrust-Vector Control

Pilot ratings from the evaluation of longitudinal thrust-vector control independent of aircraft pitch attitude (ITVC) are shown in Fig. 26 and summarized under Cases LI1-LI15 in Table A-VII in Appendix A. Lateral ITVC was not considered. The pilots were instructed to rate aircraft flying qualities based on their ability to perform longitudinal-position control tasks using thrust-vector-angle rotation with a minimum of pitch-attitude changes. Note that for the other parts of the UARL program the pilots could change the thrust vector to offset the effects of the mean wind acting through the longitudinal drag parameter. However, he was not permitted to use it for general position control. For the ITVC evaluation he was required to attempt to control longitudinal position exclusively with thrust-vector-angle rotation.

Two Level 1 configurations (BC1, BC4) and a Level 2 configuration (BC2) were evaluated with ITVC.

For configuration BC1, with thumb-switch thrust-vector control and control-stick pitch control and the thrust-vector angle displayed on the contact analog (Fig. 26(a)), the best ratings obtained were nearly as good as those for conventional thrust-vector control through attitude changes (PR = 2 to 2.5 for BC1 with conventional control). The pilots did not find it difficult to control aircraft position with the thrust-vector angle while regulating attitude. The lack of extensive experience with ITVC may have been the major reason for the slightly poorer ratings compared with those for conventional control.

Pilot B also evaluated ITVC (thumb-switch thrust-vector control) for configuration BC1 with only an instrument-panel display of thrust-vector angle. For this case his rating was somewhat poorer because alternating his attention between the contact analog and the thrust-vector-angle panel display increased the difficulty of the control task. With the thrust-vector angle on the contact analog (the cross symbol moved vertically on the right side of the screen to indicate angle) the pilot could derive both longitudinal position and thrust-vector-angle information simultaneously. It should be noted that a thrust-vector-angle display was essential to the performance of the longitudinal maneuvering task. Without such a display longitudinal position could not be stabilized. The pilots apparently controlled thrust-vector angle as an inner loop and aircraft position as an outer loop. This is similar to closure of the pitch-attitude loop as an inner loop for conventional V/STOL aircraft control systems (Ref. 8).

For configuration BC4 the best pilot ratings for ITVC with thumb-switch thrust-vector control (PR $\sim$ 4 for $\dot{\gamma}$ = 20 deg/sec, Fig. 26(a)) were slightly poorer than those for conventional control (PR = 3 to 3.5). Configuration BC4 (a high-drag configuration) is Level 1 but more responsive to gusts. The larger position 'isturbances associated with BC4 appear to be the reason that the best overall ratings for this configuration were assigned with $\dot{\gamma}$ = 20 deg/sec. Rapid thrust-vector angle rates were needed to control position. For BC2, the Level 2 configuration (with conventional control), the best rating for thumb-switch ITVC (PR = 4) was slightly better than that for conventional attitude control (PR = 4.5 to 5). Configuration BC2 is Level 2 because of its lightly damped attitude dynamics. It may be that control of this configuration was improved with ITVC, because it was not necessary to change attitude to move the aircraft longitudinally. As a result, attitude motion was not excited to the extent that it was for the conventional control system and the pilot's workload may have been reduced.

Results from the evaluation of stick thrust-vector-angle control and thumb-switch attitude control are shown in Fig. 26(b). The thrust-vector-angle change per inch of stick input (or sensitivity) was varied in this study, but the rate-of-change of pitching moment from the thumb switch was fixed at a predetermined satisfactory value. A 0.1-sec lag in thrust-vector-angle response was also simulated. For configuration BC1 this method of ITVC was satisfactory (Fig. 26(b)), i.e., ratings were similar to those for thumb-switch thrust-vector control. Recall that BC1 has very stable attitude dynamics and little attitude or position response to turbulence. However, configuration BC4 could not be controlled with the stick ITVC and thumb-switch attitude control system. This was due to the difficulty in controlling attitude with the thumb switch for this gust sensitive configuration. The pilot could not pay the necessary attention to attitude control and still control position with ITVC. The result was eventual loss of control. The same comments apply to this type of control for configuration BC2.

The UARL evaluation of thrust-vector control independent of aircraft attitude indicates that it could be an acceptable substitute for conventional attitude control, when properly implemented. For large aircraft with Level 1 dynamics the use of ITVC should provide satisfactory flying qualities while enabling the pilot to avoid pitch (or roll) attitudes that could lead to ground strikes. For aircraft having large drag parameters (X_u; Y_v) ITVC would also enable the pilots to control position without the large attitude angles that result for such aircraft with conventional position control through attitude. However, the results from this study for an aircraft with large drag parameter (BC4, $X_u = Y_v = -0.2$) indicate that position control for such aircraft remains moderately difficult even with ITVC.

7. <u>Rate-Command/Attitude-Hold Control</u>

The attributes of rate-command/attitude-hold control are that it (1) provides a pitch (roll) rate response proportional to pilot stick commands, and (2) maintains aircraft trim attitudes while enabling the pilot to center his control stick (see Section II.B.1.h. for background). Rate-command/attitude-hold control can be developed with a conventional rate and attitude stabilized V/STOL, by inserting an integration between the pilot's control inputs and the aircraft attitude response. However, to provide satisfactory flying qualities the rate damping and attitude stabilization must be increased to offset the phase lag introduced by the integrator. This can be accomplished by increasing the damping ratio, ζ , of the aircraft's oscillatory roots (with rate damping) and increasing the natural frequency, ω_n, of these roots (with attitude stabilization) beyond the attitude-loop crossover frequency ($\omega_c \approx 2.5$ to 3.5 rad/sec, Ref. 8). Representative effects of changes in ζ and ω_n on the magnitude and phase characteristics of the open-loop pilot-pitch attitude (with no pilot compensation) transfer function are shown in Fig. 27. These results show that increasing ω_n reduces the phase lags near the crossover frequencies $\omega_c \approx 2.5$ to 3.5 rad/sec (and, correspondingly, the pilot lead compensation) more than increasing ζ . Cases LR1-LR15 were evaluated in this study. Flying qualities results for the case are listed in Table A-VIII in Appendix A.

a. <u>Pilot Ratings</u>

The pilot ratings in Fig. 28 for a configuration having the basic air-frame dynamics (i.e., speed stabilities and drag parameters) of BC1 show the effects of both ζ and ω_n for rate-command/attitude-hold control. Ratings are shown in Fig. 28(a) for ω_n = 2.80, 3.44, 6.30 and 7.40 rad/sec. Again, the pitch and roll dynamic characteristics were identical. Several values of ζ were considered for ω_n = 2.8 and 6.3. The data in Fig. 28(a) indicate that for ω_n in the region of the pitch- and roll-loop crossover frequencies, e.g., ω_n = 2.80 and 3.44, satisfactory ratings cannot be achieved even with ζ values approaching 1.0. However, for $\omega_n \geq 6.3$ satisfactory ratings resulted for ζ values of 0.5 and possibly lower. Configuration BC4 was evaluated with two natural frequency values (ω_n = 4 and 5 rad/sec) different from those for BC1 to provide a relatively complete map of the effects of natural frequency. There is a significant difference between the moving- and fixed-base data for BC4, but, again, ratings are better for the larger ω_n. It appears, also, that damping ratios in the neighborhood of 0.7 are probably necessary to insure satisfactory flying qualities for these ω_n values. A rate-command/attitude-hold control system was also evaluated for hover and low-speed flight in a previous Boeing study (Ref. 16). In that study an ω_n of 5 rad/sec with ζ = 0.9 resulted in good ratings for lateral flying qualities (PR = 2 to 3 for the optimum control sensitivity) and unsatisfactory ratings were obtained for ω_n = 2.5 rad/sec with $\zeta = 0.9$. These results agree fairly well with the UARL data.

Although the UARL pilots rated a number of the rate-command/attitude-hold test cases satisfactory (LR4, LR6, LR8 and LR15, Table A-VIII, in Appendix A) their comments indicate that it provided no particular benefits for hover and low-speed flight operation. For this type of flight the pilots did not hold given aircraft pitch and roll attitudes sufficiently long to appreciate the fact that trim attitudes could be maintained with the stick centered. Also, the UARL study was conducted without stick centering forces and small offsets from the stick null position resulted in attitude errors when the pilots attention was diverted elsewhere. Finally, it should be noted that the dynamic response portion of MIL-F-83300 (paragraph 3.2.2.1) which stipulates the pitch and roll dynamics necessary for satisfactory flying qualities does not apply to rate-command/attitude-hold control. This paragraph excludes pitch and roll dynamics having an aperiodic root at the origin and admits oscillatory dynamics with $\zeta = 0.3$, providing ω_n is ≥ 1.1 rad/sec. The data from the UARL study show that rate-command/attitude-hold systems are acceptable, although they have an aperiodic root at the origin. However for them to be acceptable, their ω_n must be much greater than 1.1 rad/sec if ζ is only 0.3. Of course, it was not intended that MIL-F-83300 should necessarily apply to rate-command/attitude-hold systems.

b. Control Sensitivities

Longitudinal and lateral control sensitivities from the rate-command/attitude-hold study are shown in Fig. 29. The control sensitivities increase with ω_n but do not show well-defined trends with ζ. The increases in $M_{\delta e}$ and $L_{\delta a}$ with ω_n are to be expected, since larger sensitivities are needed to offset the restoring moments resulting from this large "spring constant". Upper and lower boundary values for control sensitivity, computed from the MIL-F-83300 requirements for control response, are shown in Fig. 29. Two sets of boundary levels, corresponding to two different values of ω_n, are shown for each of the configurations (BC1 and BC4) evaluated. All of the sensitivities affected by the boundary limits shown lie within the acceptable region.

8. Effect of Motion on Pilot Ratings for Longitudinal and Lateral Control

The results of a comparison of pilot ratings for longitudinal and lateral control from moving-base (MB) and fixed-base (FB) evaluations of identical test cases are summarized in Table XI. There the FB-ratings for the different test cases are categorized according to rating level, i.e., satisfactory, unsatisfactory, and unacceptable. The associated MB ratings for the test cases in a given FB rating category are then listed according to whether the MB ratings were better than, equal to, or worse than the corresponding FB rating. The moving-base ratings were consistently no better than, and generally worse than, the fixed-base ratings for the same test

cases. This trend holds for all three of the FB rating categories. Relatively high frequency pitch and roll control inputs must generally be used to control longitudinal and lateral position properly. There may have been a tendency for the pilots to make more abrupt control commands and also to tolerate disagreeable attitude motions (observed on the visual display) more for fixed-base operation. The addition of motion would have made the pilot more aware of undesirable characteristics in test case dynamic responses. This effect could have overshadowed the benefits of added control cues through motion and caused the poorer moving-base ratings.

TABLE XI

EFFECT OF MOTION CUES ON PILOT RATINGS
FOR LONGITUDINAL AND LATERAL CONTROL

Fixed-Base (FB) Rating-Level, Number of Ratings	Corresponding Moving-Base Rating		
	Better than FB Number/Percent of Total	Equal FB Number/Percent of Total	Worse than FB Number/Percent of Total
Satisfactory, 18	4/22	3/17	11/61
Unsatisfactory, 20	7/35	1/5	12/60
Unacceptable, 6	1/17	4/66	1/17

B. Control-Moment Usage

The discussion of the control-moment usage data is presented in four parts. In part 1 the effects of a number of aircraft, control system and task parameters on pitch, roll and simultaneous pitch and roll control-moment usage (as defined by the moment levels exceeded 5 percent of the time) are described. These results were obtained from experiments in which essentially unlimited control moment was available to the pilot. Specifically, the effects of turbulence intensity, aircraft speed stability and drag parameters, flying qualities level, control system lags, motion coupling, and subtask are described. A comparison is also shown between actual simultaneous pitch- and roll-control-moment usage and hypothetical maxima and minima for such simultaneous usage. These results provide insight into the degree to which pilots make simultaneous control commands. In part 2 results from the study of control-moment limits are discussed. The percent time that total control-moment commands exceeded the installed limits are presented

and correlated with the pilot acceptance of the limits. Parts 3 and 4 are concerned with control-moment usage results for the unconventional control systems considered: independent thrust-vector control and rate-command/attitude-hold control, respectively.

In general, comparisons with the MIL-F-83300 specification for control moments are not made in the discussions of control-moment usage. There are two reasons for this: (1) control-moment comparisons were already made in the discussion of the flying qualities results for the control-moment limits study (Section III.A.3) and, (2) the control-moment usage data are described in terms of the 5-percent-exceedance levels which were shown to be lower than the control-moment limits required for pilot acceptance (Section III.A.3). However, the 5-percent-exceedance levels do provide a useful measure for evaluating control-moment usage (see Section II.D.1.b.). Additional control moment usage data are shown in Appendix E. Exceedance plots based on control moment usage in the maneuvering subtasks are presented there which further illustrate the effects of a variety of aircraft and control system parameters.

1. <u>Effects of Aircraft, Conventional Control System and Task Parameters on Control-Moment Usage</u>

a. <u>Turbulence Intensity</u>

The effects of turbulence intensity ($\sigma_{u_g} = \sigma_{v_g}$) are presented in Figs. 30 and 31 and also listed in Table C-I in Appendix C. The data in Fig. 30 are for configuration BC1 which requires little pilot compensation or "lead" (Level 1) and is relatively unresponsive to turbulence. That is, the configuration has a relatively high level of stability augmentation ($M_q = L_p = -1.7$ and $M_\theta = L_\phi = -4.2$) and the stability derivatives which describe the moments and forces caused by turbulence, speed stability and drag parameters, respectively, are small ($M_ug = -L_vg = 0.33$, $X_u = Y_v = -0.05$). Figure 31 presents results for configuration BC6 which is Level 2, and more responsive to gusts ($M_ug = -L_vg = 1.0$, $X_u = Y_v = -0.20$).

For configuration BC1 (Fig. 30) the moment levels corresponding to the 5-percent exceedance level generally increase with turbulence intensity for all tasks, although there is appreciable scatter in the results. Also, none of the 5-percent moment levels (pitch, roll, or combined) scale linearly with turbulence. That is, there is a factor of about 2.4 increase in rms turbulence intensity from 3.4 ft/sec to 8.2 ft/sec but the 5-percent control-moment levels at 8.2 ft/sec are not 2.4 times as great as those for 3.4 ft/sec. The reason the control-moment levels do not scale may be that the control inputs necessary for task performance and the pilot's inadvertent inputs form a bias 5-percent moment level upon which the turbulence

effects are superimposed. Of course, the 5-percent moment level for pitch has an additional bias due to the 10 kt mean wind acting through M_u. This bias moment is approximately 0.18 rad/sec^2.

The levels for configuration BC6 (Fig. 31) are significantly larger than those for BC1. This is to be expected because of the greater response of BC6 to gusts, maneuvering airspeeds and the mean wind. For example, the bias moment in pitch for BC6 due to the mean wind is approximately 0.53 rad/sec^2. The 5-percent roll control-moment levels for BC6 are generally somewhat smaller than those for pitch, probably also because of the increased bias moment in pitch from the mean wind. In addition, the roll moment levels for BC6 show more of a tendency to scale with turbulence than those for configuration BC1. Turbulence has a greater effect on control-moment requirements for BC6 than BC1 because of the greater response of BC6 to gusts. Consequently, it might be expected that in the absence of significant mean-wind effects, as is the case for roll, the control-moment levels for BC6 would exhibit a greater tendency to scale with turbulence.

b. Speed-Stability Parameter

In Fig. 32 and Table C-1 in Appendix C, control-moment results are presented for configurations BC5 and BC4 which show the effects of aircraft speed stability ($M_u g$, $L_v g$). Both of these configurations have sufficient stability augmentation to yield Level 1 flying qualities and each has drag parameters of $X_u = Y_v = -0.2$ per sec. Their speed-stability parameters differ by a factor of three, however ($M_u g = -L_v g = 0.33$ for BC5 and 1.0 for BC4). The levels in Fig. 32 show an appreciable increase with speed stability for all three control-moment categories. For the individual-axis control moments the increment due to increased speed stability is greater for pitch where the effects of the mean wind are significant. Also, for none of the moment categories does the change in the 5-percent exceedance level scale directly with the factor of three change in speed stability. This would tend to indicate that the control-moment levels required to arrest and initiate position rates and those caused by random pilot inputs are appreciable. If they were not, we might expect 5-percent levels to scale with speed stability because the remaining disturbance moments due to maneuvering airspeed, the mean wind and turbulence all scale with speed stability. It is interesting to note here, also, that MIL-F-83300 accounts, to an appreciable extent, for the effects of speed stability on required control moments. This is accomplished by stating that the required aircraft response must be demonstrated at the airspeeds involved in task performance (paragraph 3.2.3.1, Ref. 1). Also, in the control-moment limit study the specification was found to be adequate for configurations having both large ($M_u g = -L_v g = 1.0$) and small ($M_u g = -L_v g = 0.33$) speed-stability parameters (Section III.A.3).

c. Drag Parameter

The change in the reference control-moment levels with drag parameter (X_u, Y_v) are shown in Fig. 33 and Table C-I in Appendix C. Configurations BC1 and BC5 are identical except that the drag parameters for BC5 are four times those for BC1 (-0.20 versus -0.05). The results in Fig. 33 show a small general increase in the levels for configuration BC5 which has the larger drag parameters. Increased drag parameters result in larger position disturbances from turbulence. However, maneuvering position rates are generally smaller because of the larger drag forces and these rates are easier to arrest because of the increased position damping. The increased disturbances due to turbulence would probably necessitate larger control-moment levels while the other effects of drag parameter should not increase, and could reduce, the required control levels. That is, the attitude angles and rates-of-change need not be as great to arrest position rates for configurations with larger drag parameters. It appears then, from the results in Fig. 33, that the effects of turbulence may have been dominant since the 5-percent levels increased slightly with drag parameter. The increase would appear to be relatively small, however, for a large change in drag parameter. Certainly, the effects of changes in drag parameter are less than those for the changes in speed-stability parameter that were examined.

d. Level of Flying Qualities

The V/STOL Flying Qualities Specification (MIL-F-83300, Ref. 1) defines three flying qualities levels. Level 1 flying qualities are "clearly adequate for the mission," Level 3 are such that the "aircraft can be controlled safely but pilot workload is excessive or mission effectiveness is inadequate, or both" and Level 2 flying qualities lie between these extremes. The control-moment usage data observed for configurations with Level 1, Level 2, and Level 3 dynamic characteristics are shown on Fig. 34. Results are presented there (and also in Table C-I in Appendix C) for configurations BC4, BC2, and BC3 (Level 1, 2, and 3 configurations, respectively), which have identical speed-stability parameters ($M_u g = -L_v g = 1.0$). The drag parameters are not identical for each configuration, but drag parameter has a much smaller effect on the 5-percent control-moment level (Fig. 33). There is a general increase in these exceedance moment levels for configurations which fall into the three flying qualities levels of paragraph 3.2.2 in Ref. 1 (Fig. 34) for all three moment categories. That is, as the flying qualities are degraded through reductions in stability augmentation, the control moments used increase. This would indicate that stability augmentation does a more efficient job of compensating the aircraft dynamics and attenuating turbulence inputs than does the pilot. It would appear also that the required levels of installed control moments are decreased with improved aircraft flying qualities.

e. Control System Lags

Control lags appeared to have little effect on control-moment usage. Five percent moment levels for configurations having control system lags are shown in Figs. 35 and 36 (configurations BC5 and BC4, respectively). These data are also summarized in Table C-II in Appendix C. The addition of control lags to BC5, which is Level 1 and has low turbulence response, resulted in a small decrease in the 5-percent levels for pitch and combined control-moment usage, but the levels for roll do not show a consistent change. The effects of control lag on the 5-percent levels for configuration BC4 (Fig. 36) are even less consistent than those for BC5. Configuration BC4 is also Level 1 but more responsive to turbulence than BC5.

f. Inter-Axis Motion Coupling

The effects of both rate and control coupling on the pitch moment levels exceeded 5 percent of the time for configuration BC1 can be seen in Fig. 37 and Table C-IV in Appendix C. Control coupling ($M_{\delta a}/L_{\delta a} = L_{\delta e}/M_{\delta e}$) is treated as a parameter in the three plots of Fig. 37 which correspond to different rate-coupling levels ($M_p = -L_q$). The effects of control coupling alone are shown in Fig. 37(a) where $M_p = -L_q = 0$. These data indicate no significant increase in M_{c_5} for a change in control coupling ratios from 0 to $M_{\delta a}/L_{\delta a} = -L_{\delta e}/M_{\delta e} = 0.5$. Recall that for satisfactory pilot ratings control coupling ratios should be kept below 0.25 (Section III.A.5). Consequently, the results in Fig. 37(a) indicate that for acceptable levels of control coupling, the control-moment usage is not changed significantly from that for no control coupling.

However, the results in Fig. 37 show that rate coupling does influence control-moment usage. By comparing the fixed-base data for no control coupling across Figs. 37(a), (b), and (c), it can be seen that pitch control-moment usage increases with rate coupling level. Rate coupling levels greater than $M_p = -L_q = 1$ appear to be unacceptable if satisfactory flying qualities are to be achieved (Section III.A.4). The results in Fig. 37 would indicate that such rate-coupling levels could result in approximately a 10-percent increase control-moment usage.

g. Subtask

Four major subtasks were performed by each pilot during the control-moment-usage study --- maneuvering or air taxi, quick stop, turn-over-a-spot and hover. Two of these, the maneuver and quick-stop subtasks, could be further subdivided according to the direction (longitudinal or lateral) in which the subtask was performed. The effects of each subtask on the 5-percent control-moment-usage level can be seen in Fig. 38 and Table C-I in Appendix C. These data were all obtained for the 3.4 ft/sec turbulence

intensity level and with the 10-kt mean wind from the north. Note that the aircraft was always headed into the wind except for the turn maneuver.

The subtask for which the pitch and roll 5-percent exceedance level was most often the largest was the quick stop (Fig. 38); the next largest values were for the maneuvering subtask. The lowest levels (pitch and roll) were most often recorded for hover and the next lowest for the turn subtask. The quick stops involve somewhat larger maneuver rates than air taxi and these rates are arrested abruptly. Consequently, it is not surprising that the largest control moments were used there. Hover, on the other hand, generally requires smaller control inputs and the pilots tended to make fewer inadvertent inputs for this subtask. This was generally the situation for turn as well, except that the pilots at times introduced large pitch and roll attitudes for lightly damped configurations, e.g., BC2 and BC3.

The combined control-moment-usage levels are shown with the maneuver and quick-stop subtasks divided into their longitudinal (x) and lateral (y) components. The lateral quick stops resulted in the largest 5-percent-exceedance levels for combined usage and the next largest levels were used for the lateral maneuvers. The combined usage for lateral maneuvering and quick stops may have been larger than that for the same longitudinal subtasks because the lateral subtasks required appreciable control moments while pitch moments were also necessary to compensate for the mean wind. For the longitudinal subtasks pitch moments were needed to perform the maneuvers in the mean wind but roll inputs were small. The lowest levels for simultaneous usage were recorded for the hover task.

h. Simultaneous Usage

An indication of the pilot's tendency to make pitch and roll control inputs simultaneously can be obtained by comparing the sum of the moment levels used for the individual axes with the actual simultaneous usage levels. If the 5-percent-exceedance moment levels for pitch and roll are added, the resulting control moment is that level which would be exceeded 5 percent of the time if the pitch and roll control moments were used simultaneously. The sum of these levels then represents a theoretical maximum for simultaneous moment usage. Also, a practical minimum level for combined usage can be developed if it is assumed that the pitch and roll inputs are independent, i.e., that the pilot does not intentionally correlate his pitch (roll) inputs with the roll (pitch) control motions.

Curves representing the hypothetical maxima and minima for the simultaneous control usage 5-percent exceedance level are shown in Fig. 39 along with the 5-percent moment levels for actual simultaneous usage. The results presented for all six configurations are for the hover subtask only (Table C-I in Appendix C). Similar data were not available in sufficient quantity

for the other subtasks. The levels representing the upper curve indicate the 5-percent moment levels which would occur if all the pilot's pitch and roll inputs were made simultaneously. The points on the lower curve are the square root of the appropriate sum of the squared 5-percent levels for pitch and roll. That is, it was assumed that the pitch and roll control moments were independent and could be represented by Gaussian probability distributions (the nearly linear curve for hover in Fig. 5 indicates that the Gaussian assumption is reasonable). It can be shown, then, that the square root of the sum of the squares of the individual 5-percent levels represents the simultaneous usage 5-percent level. The remaining curve in Fig. 39 shows the 5-percent levels for actual simultaneous control usage. This curve lies about midway between the two extremes. These results would indicate that, for the hover subtask at least, the minimum total installed control moment for both pitch and roll could be set somewhat less than the sum of the maximum used for individual axis control. However, this total level must still be greater than a level which would be satisfactory for single-axis control.

2. Percent Time Control Moment Commands Exceed Limits

The control-moment limit study (Section III.A.3) was conducted to determine (1) acceptable levels of installed moments for several V/STOL configurations (BC1, BC4, BC5 and BC6) and (2) whether these limits correlated with the 5 percent exceedance levels measured with unlimited control moments. It was found in that study that control moments greater then the 5-percent levels were needed for pilot acceptance. The results presented here give some indication of the acceptability of installed control moments in terms of the percent time the total control command actually exceeds these limits.

Figure 40 contains plots of the percent time total pitch and roll control commands exceeded the installed moments during the maneuvering subtask versus the magnitude of the installed moments (Table C-III in Appendix C). These maximum available control moments, CM_m, are stated as multiples of the average moment levels exceeded 5 percent of the time with unlimited available moments, CM_5. Note that CM_5 is different for each basic configuration. As would be expected, the percent time the total moment command exceeded the installed moments decreased as CM_m became larger. However, the exceedance percentages become very small as CM_m approaches those levels needed for pilot acceptance ($CM_m \approx 1.2$ to $1.3\ CM_5$ for BC1, $\approx 1.0\ CM_5$ for BC5 and ≈ 1.2 to $1.3\ CM_5$ for BC4 and BC6). For pitch control the exceedance percentages at acceptable CM_m range from about 1.5 percent (average fixed- and moving-base results for BC1) down to almost zero. For roll control the percentages are about the same magnitude. It would appear from these limited results that for pilot acceptability, installed control moments must be set at levels which will not be exceeded often in flight.

3. Control-Moment Usage for Independent Thrust-Vector Control

Independent thrust-vector control might be expected to reduce the requirements for control moments since it eliminates the need to change attitude in order to maneuver the aircraft. However, control moments are still required to attenuate the attitude response to gusts and trim the moments due to airspeeds (developed from maneuvers and the mean wind) acting on the speed-stability parameters. Pitch control-moment- and thrust-vector-angle-usage data are listed in Table C-V in Appendix C.

In Fig. 41 the pitch and control-moment 5-percent exceedance levels for ITVC and conventional pitch attitude control are presented for configurations BC1 and BC4. For both configurations the value of M_{c_5} for ITVC is consistently somewhat smaller than that for conventional attitude control.

Exceedance computations were also performed on measured thrust-vector-angle data from the study of ITVC (Table C-V in Appendix C). For the turn maneuver with configuration BC1 the 5-percent thrust-vector-angle exceedance levels ranged from approximately 2 to 8 deg.

4. Control-Moment Usage for Rate-Command/Attitude-Hold Control

Pitch control-moment-usage results for the rate-command/attitude-hold control system are shown in Fig. 42 for three values of the natural frequency of the oscillatory dynamics (ω_n = 2.8, 3.44 and 6.3 rad/sec) and several levels of the damping ratio, ζ. These data are presented for test cases having the basic airframe stability derivatives of configuration BC1. As the damping ratio was increased for both ω_n = 2.8 and 6.3 rad/sec, the configuration became easier to control and the 5-percent exceedance moment level decreased. However, for the two test cases yielding the best fixed-base ratings (ω_n = 3.44, ζ = 0.87, PR = 4 and ω_n = 6.3, ζ = 0.47, PR = 2.5) the fixed-base 5-percent moment usage levels were still greater than the corresponding levels for BC1 with conventional attitude control (see Fig. 41).

SECTION IV

RESULTS OF HEIGHT CONTROL STUDIES

The height control results are discussed in two parts. In part A, the flying qualities data, i.e., pilot opinion ratings and control sensitivities, are discussed and compared with the applicable paragraphs of MIL-F-83300. In part B, the measured thrust-usage data are described. Background material on the experimental design and procedures are contained in Section II. The flying qualities data, pilot comments and measured thrust-usage results from the UARL pilot evaluations are summarized in Appendices A, B and C, respectively. Results from the Calspan pilot evaluations discussed in this section are summarized in Appendix D.

A. Flying Qualities Results

Four separate investigations were conducted during the height control study. These investigations were concerned with (1) the effects of height velocity damping with effectively unlimited thrust-to-weight ratio, (2) the interaction between height velocity damping and thrust-to-weight ratio, (3) lags and delays in the thrust response, and (4) incremental thrust through stored energy.

1. Height Velocity Damping

a. Pilot Opinion Ratings

The effects of height velocity damping, Z_W, on pilot opinion for effectively unlimited thrust-to-weight ratio, $T/W > 1.15$, are presented in Fig. 43 and summarized in Table A-IX (Cases HZ1 through HZ4 and HZ25 through HZ28). Data are shown in Fig. 43 for one Calspan pilot and two UARL pilots. The Calspan pilot evaluations were conducted with no simulated winds and with the simulator in the moving-base mode, while the UARL pilot results were obtained for fixed- and moving-base simulator operation and the standard wind simulation (10-kt mean wind from the north and 3.4 ft/sec gusts along the aircraft x and y body axes). The configurations simulated during these evaluations were BC1 and BC4 which both have Level 1 longitudinal and lateral flying qualities. The ratings from all three pilots are unsatisfactory (and quite similar) for less damping than about $Z_W = -0.35$ per sec. For $Z_W = 0$ the ratings ranged from 8 to 10 and the pilots all commented that stabilizing aircraft vertical motion was extremely difficult. They also indicated that it would probably be impossible to perform any other task, such as a lateral air taxi, in addition to controlling height (see Appendix B, Table B-VIII). The improvement in rating with increased levels of height velocity damping correlates well with the associated reduction in

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requirements for pilot lead compensation. The phase lags in the height response to height errors are shown in Fig. 44. Pilots must compensate for these lags at frequencies important to closed-loop height control (0.5 to 1.0 rad/sec; Ref. 7). It is apparent in Fig. 44 that the lead requirements diminish with additional Z_w.

The specification for minimum height velocity damping (paragraph 3.2.5.4) indicates that, for effectively unlimited T/W ($T/W \geq 1.10$), satisfactory height control characteristics can be obtained with $Z_w = 0$. The results in Fig. 43 indicate that the flying qualities are unacceptable without height velocity damping. If the pilot's only task were to control height he may be able to stabilize the altitude loop with $Z_w = 0$. However, the UARL results indicate that if he is also expected to perform tasks involving longitudinal, lateral or directional motion, altitude errors of at least ±20 ft could be expected. In addition, the precision with which the other tasks could be performed would be seriously degraded by the attention which would have to be given to height control.

b. Collective Control Sensitivities

Pilot-selected control sensitivities from the investigation of height velocity damping are shown in Fig. 45. The sensitivities change little with Z_w although there is a tendency for them to become larger as damping is increased. The minimum permissible MIL-F-83300 boundaries for collective control sensitivity are also plotted in Fig. 45. These boundaries are stated in terms of achieving a climb rate of 100 ft/min 1.0 sec after an abrupt 1-in. control input. Consequently, the boundaries increase as the damping is increased. The control sensitivities from this study all lie well within the allowable range, but they are much closer to the minimum boundary than the maximum. The maximum permissible collective control sensitivities range from $Z_{\delta_c} = 12.5$ to 18.1 as Z_w changes from 0 to -0.8.

2. Interaction Between Height Velocity Damping and Thrust-to-Weight Ratio

Figure 46 contains results which demonstrate the interaction between Z_w, T/W and pilot ratings. These data are also listed in Table A-IX, Cases HZ1 through HZ28. In Fig. 46 pilot ratings are presented on a plot of total height velocity damping, Z_{w_T}, versus T/W. Similar plots of the results from other height control studies were used to formulate height control power requirements for MIL-F-83300. The data on Fig. 46 were obtained for UARL and Calspan pilots and for fixed- and moving-base flight simulator operation. The basic configuration evaluated was BC1. For most of the data points, Z_{w_T} consisted of equal parts of aerodynamic (Z_{w_a}) and SAS (Z_{w_s}) height velocity damping. However, as indicated in Fig. 46 some of the cases were evaluated with either Z_{w_a} or Z_{w_s} (but not both) set to

zero. It should be noted that Z_{w_S} is provided only within the available T/W. That is, thrust used for damping is instantaneously unavailable for control. Also shown in Fig. 46 are Level 1, 2 and 3 boundaries for height control power from MIL-F-83300.

A definite trade off between the effects of T/W and Z_{w_T} on pilot opinion is indicated by the results in Fig. 46. For example, as T/W is increased at constant Z_{w_T}, ratings generally improve. Conversely, as the damping is increased for a given T/W, rating also generally improves. These effects tend to justify, to some extent, the shape of the MIL-F-83300 boundaries. However, the data in Fig. 46 are not in complete agreement with these boundaries. One notable exception occurs for the Level 1 boundary at T/W = 1.10 where the UARL results would indicate that total damping greater than -0.25 is necessary for satisfactory ratings. That is, the boundaries in Fig. 46 imply that a T/W > 1.10 is required for a satisfactory rating at Z_{w_T} = 0. However, the results shown previously in Fig. 45 indicate that even an "unlimited" T/W will not provide satisfactory ratings for Z_{w_T} = 0. The UARL data would indicate, then, that another boundary line which excludes damping levels smaller than -0.25 should be added to Fig. 46. If this boundary were present the UARL data would also support the movement of the line separating Level 1 and 2 regions to the left. That is, it appears that for a given Z_{w_T} less T/W is needed to place a configuration in a Level 1 category than MIL-F-83300 requires.

The interaction between aerodynamic, Z_{w_a}, and SAS, Z_{w_S}, height velocity damping shown in Fig. 46 merits discussion. A decelerating force which is proportional to descent velocity is available to arrest sink rates in aircraft which have Z_{w_a}. Such force may have an appreciable effect on height control for aircraft with limited installed T/W. This increased decelerating force is not available in aircraft with only Z_{w_S}. Ratings showing the effects of Z_{w_a} and Z_{w_S}, with T/W as a parameter, are presented in Fig. 47. For all the cases shown, the total damping was Z_{w_T} = -0.25, but the relative amounts of Z_{w_a} and Z_{w_S} were varied. For T/W = 1.02 it appears that the improved ability to arrest sink rates resulting from increased Z_{w_a} had a significant impact on flying qualities. As Z_{w_a} was changed from 0 to -0.25, pilot rating improved by two units. As T/W was increased the decelerating force from Z_{w_a} became less important since the pilot had sufficient T/W to adequately ascend and arrest descents. This is reflected in the smaller change in rating over the same Z_{w_a} interval for the larger T/W values. In fact, the moving-base ratings for T/W = 1.10 show almost no variation with Z_{w_a}.

3. Lags and Delays in Thrust Response

The effects on pilot rating of first-order lags and a 0.1-sec delay in the thrust response are presented in Fig. 48 and Table A-X (Cases HL1 through

HL8). Two values of lag time constant, $\tau_h = 0.3$ and 0.6 sec were evaluated at three levels of Z_{w_T}: -0.25, -0.35 and -0.50. The thrust-to-weight ratio was held constant at 1.05 and configuration BC1 was used for the longitudinal and lateral flying qualities. Except for $Z_{w_T} = -0.50$, rating deteriorates with increasing τ_h. The decrement appears to be related to Z_{w_T} as well as the change in τ_h (Fig. 48). That is, rating is somewhat less sensitive to τ_h for the higher damping levels. The upward shift in the curves with Z_{w_T} is expected since the phase lag in height response at any given τ_h, and hence the pilot's lead compensation, decreases with increasing damping (see Fig. 44). Note also, that the addition of a 0.1-sec delay had little effect on rating (Fig. 48). Pilot rating for $Z_{w_T} = -0.35$ with $d_h = 0.1$ sec and $\tau_h = 0$ is equal to that for no delay, and for $\tau_h = 0.3$ the rating with a 0.1-sec delay is only a half unit poorer than for no delay.

The specification for lags in thrust response (paragraph 3.2.5.2) is phrased in such a way that, with no delays, a first-order control lag time constant of up to 0.3 sec is permissible. For a $d_h = 0.1$ the specification would permit a lag of $\tau_h \approx 0.2$ sec. The UARL data in Fig. 48 would indicate that the specification is reasonable, providing the aircraft has a Z_{w_T} of at least -0.25 to -0.35 per sec. This is the range of minimum values of damping found to be acceptable in the height control studies with no lags. The previous results (e.g., Fig. 43) would indicate that for $Z_{w_T} = 0$, $\tau_h = 0.3$ would be completely unacceptable. Also, the specification does not account for the reduction in phase lags contributed by τ_h or d_h, and the associated improvement in rating, which can be achieved with increased levels of Z_{w_T}. This effect is illustrated in Fig. 48 and is discussed in detail in Ref. 7.

4. Incremental Thrust Through Stored Energy

The effects of incremental thrust through stored energy (see Section II.A.2.d for background) were investigated with a height control configuration that was unsatisfactory without the stored energy contribution. However, the longitudinal and lateral dynamics were quite easy to control (configuration BC1). For height control the installed T/W was only 1.02 and $Z_{w_T} = Z_{w_S} = -0.35$, i.e., the pilot had no additional decelerating force from Z_{w_a} when descending. Without the incremental thrust from stored energy, height control was unsatisfactory (PR = 4). The change in rating was evaluated for incremental thrust-to-weight ratios of $\Delta T/W = 0.13$ and 0.28 and for decay time constants of $\tau_\Delta = 0.05$, 0.10 and 0.20 sec (Cases HS1 through HS5, Table A-X). With $\Delta T/W = 0.13$, an improvement in rating was not evident until $\tau_\Delta = 0.20$ (Fig. 49). For the larger thrust increment, $\Delta T/W = 0.28$, a general improvement in rating occurred for $\tau_\Delta = 0.10$ sec. For both the $\Delta T/W = 0.13$, $\tau_\Delta = 0.20$ and $\Delta T/W = 0.28$, $\tau_\Delta = 0.10$ combinations, the ratings improved by about one unit to PR = 3.0. For effectively unlimited T/W, the rating was 2.5. The results indicate that for τ_Δ values which might be typical for helicopters, i.e., $\tau_\Delta = 0.10$ to 0.20 sec, the effects of incremental thrust

through stored energy can be significant. It should be noted, also, that for height control the pilot probably does not use the stored energy effects to their fullest advantage. Height control generally involves low-frequency control motions; consequently, the stored energy in the rotor system is not used as often as it is for pitch and roll control.

5. Effect of Motion and Pilot Ratings for Height Control

Fixed-base (FB) and moving-base (MB) pilot ratings for height control are compared in Table XII. The FB ratings for the different test cases are categorized by general rating level (satisfactory, unsatisfactory and unacceptable). The associated MB ratings are then tabulated according to whether they were better than, equal to, or worse than the FB ratings. The results in Table XII are mixed and only for the unsatisfactory FB rating category is a definite result indicated. For this category the moving-base ratings were generally better than the corresponding fixed-base data. It would appear that motion helped in the control of these more difficult test cases. It may be that the motion was more beneficial for height control than for longitudinal and lateral control because the visual display provides less information on height error than it does for these other two axes.

TABLE XII

EFFECT OF MOTION CUES ON PILOT RATINGS FOR HEIGHT CONTROL

Fixed-Base (FB) Rating Level, Number of Ratings	Corresponding Moving-Base Rating		
	Better Than FB Number/Percent of Total	Equal FB Number/Percent of Total	Worse Than FB Number/Percent of Total
Satisfactory, 4	1/25	1/25	2/50
Unsatisfactory, 7	5/72	1/14	1/14
Unacceptable, 2	0/0	2/100	0/0

Consequently, motion cues would have helped more for height control. This effect may not have been evident for unacceptable FB ratings because the rating scale becomes less sensitive to such effects due to its implicit nonlinearities for the unacceptable region. That is, for test cases which are very difficult to control the differences between 7 and 8 or 8 and 9 ratings are not easy to establish and pilots tend to rate such cases similarly.

B. Thrust Usage

Thrust-usage data were obtained which show (1) the effects of Z_w, (2) the percent time that pilots attempted to exceed the installed thrust-to-weight ratio, and (3) the effects of lags. The thrust exceedance results were computed using only the pilot and total thrust commands for which $T/W > 1$. These are the collective inputs which are used to accelerate upward and to arrest sink rates. Also, thrust usage levels are given in terms of incremental thrust-to-weight ratio, i.e., $(T/W-1)$.

1. Height Velocity Damping

The effects of total height velocity damping, Z_{w_T}, on the level of incremental thrust-to-weight ratio exceeded 5 percent of the time are shown in Fig. 50 and listed in Table C-VII. Results are shown for both the collective command, $Z_{\delta_C} \cdot \delta_C$, and the total thrust command, $Z_{\delta_C} \cdot \delta_C + Z_{w_S} \cdot w$. Three levels of Z_{w_T} (0, -0.25 and -0.5 per sec) were evaluated for effectively unlimited T/W ($T/W > 1.15$). The data in Fig. 50 show that Z_{w_T} has a significant effect on the 5-percent exceedance level, $(T/W-1)_5$. The 5-percent level for $Z_{w_T} = 0$ is as much as six times that for Z_{w_T} of -0.25 or -0.5. Obviously, the stability augmentation system makes much more efficient use of the installed thrust than the pilot. Also, there generally seems to be little difference between the exceedance levels for $Z_{w_T} = -0.25$ and -0.50. It would appear that increasing Z_{w_T} above what is a minimum satisfactory level (e.g., $Z_{w_T} \sim -0.25$) does not lead to significant changes in thrust usage. Note also that for relatively well damped cases, $Z_{w_T} = -0.25$ and -0.50, the largest thrust levels are used for the landing sequence. This is to be expected, since for this subtask the pilot intentionally makes several large altitude changes. For $Z_{w_T} = 0$, however, large thrust levels are used for other subtasks in which the pilot is merely attempting to maintain constant altitude. Normally, large values of $(T/W-1)$ are not needed for such control if the height dynamics are acceptable to the pilot.

2. Limits on the Installed Thrust-to-Weight Ratio

The effects of limits on the installed thrust-to-weight ratio are discussed in terms of the percent time pilots attempted to exceed the incremental T/W available. The collective control was not physically constrained at the thrust limits for this study. The thrust limits were evident only in the way they affected height control. Consequently, if the pilot felt he

needed more thrust, he tended to move the collective lever accordingly, whether or not the installed T/W had been exceeded. Results are presented in Fig. 51 for two levels of Z_{w_T} (-0.25 and -0.50) with T/W as a parameter. For Z_{w_T} = -0.25 (note that τ_h = 0.3 for the T/W = 1.05 data) the two types of commanded thrust, $Z_{\delta_c} \cdot \delta_c$ and $Z_{\delta_c} \cdot \delta_c + Z_{w_S} \cdot w$, both exceeded the T/W = 1.02 level a large percent of the time. Fifty percent was not uncommon for $Z_{\delta_c} \cdot \delta_c$ and 20 percent was typical for the total commanded thrust. However, the percentages for T/W = 1.05 were much smaller. More often than not, the T/W = 1.05 level was never exceeded. The results for Z_{w_T} = -0.50 show the same trends, but the percent time a given level is exceeded is smaller. For example, the maximum percent time that T/W = 1.02 was exceeded for any subtask was 30 percent. Also, the only time that T/W = 1.05 was exceeded was for the landing sequence and the percentage there was relatively low. These results provide another example of SAS making more efficient use of thrust than the pilot.

3. Thrust Response Lags

Some limited data showing the effects of an acceptable first-order lag in thrust response (τ_h = 0.3) are presented in Fig. 52. For these results Z_{w_T} is -0.25 and T/W is 1.10. The 5-percent exceedance levels are generally somewhat larger for τ_h = 0.3 (and appreciably larger for the y-maneuver subtask) than for the no lag case. However, these data are too limited to permit the conclusion that significantly more thrust is needed for height control systems with lags.

SECTION V

RESULTS OF DIRECTIONAL CONTROL STUDIES

The results of the directional control studies are presented in two parts. Pilot ratings and pilot-selected control sensitivities are discussed and compared with applicable paragraphs of MIL-F-83300 in part A. In part B the measured yaw control-moment data are discussed. Background information related to the directional control experiments is contained in Section II. The flying qualities data, pilot comments, and control-moment data are summarized in Appendices A, B and C, respectively.

A. Flying Qualities Results

Three different studies were conducted during the directional control program. These studies consisted of evaluations of the effects of (1) yaw rate damping, (2) control system lags and delays, and (3) limits on yaw control moment.

1. Yaw Rate Damping

Pilot rating is plotted versus yaw rate damping level, N_r, in Fig. 53(a) for configurations BC1 and BC2. Note that these ratings are for directional control only. Three values of N_r (0, -0.5 and -1 per sec) were evaluated at N_v = 0.005. Pilot rating was marginally unacceptable (PR ~ 6.5) for N_r = 0 and marginally satisfactory (PR = 3.5 to 4) for N_r = -0.5. Ratings improved to about 2.5 with N_r = -1 for both BC1 and BC2. Recall that BC2 has Level 2 longitudinal and lateral characteristics and such dynamics result in an increase in overall pilot workload. It might have been expected, therefore, that a degradation in pilot rating of the directional flying qualities could result. However, this was not the case. The reason for the improvement in rating with damping level can be interpreted in terms of the pilot lead compensation necessary for good closed-loop directional control characteristics. As for height control, the directional lead compensation requirements are related to the open-loop phase lags of the directional dynamics (and the pilot dynamics) in the frequency range of 0.5 to 1 rad/sec (Ref. 7). These phase lags are shown in Fig. 54. It is apparent that the need for lead compensation is diminished as N_r becomes more negative.

The MIL-F-83300 requirement for directional damping (paragraph 3.2.2.2) states that for Level 1 flying qualities the yaw mode must be stable with a time constant no greater than one sec. This is approximately equivalent to specifying N_r = -1 for Level 1 flying qualities and the UARL results in Fig. 53(a) show that satisfactory ratings result for such a value. The data also indicate that a somewhat lower damping level of about -0.5 per sec

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may provide satisfactory directional control for $N_v = 0.005$. However, the value of N_v can be larger than 0.005 for helicopters and V/STOL aircraft. Since directional flying qualities generally deteriorate with increasing N_v (Ref. 7), the $N_r = -1$ Level 1 requirement appears reasonable.

Control sensitivities selected by the pilots during the yaw rate damping study are shown in the following list along with the minimum and maximum values permitted by MIL-F-83300. The UARL data from the two pilots and the moving- and fixed-base evaluations have been averaged.

N_r	UARL N_{δ_r}	MIL-F-83300 Boundaries for N_{δ_r} Minimum	MIL-F-83300 Boundaries for N_{δ_r} Maximum
0	0.207	0.210	0.804
-0.5	0.236	0.244	0.935
-1	0.299	0.282	1.080

The UARL control sensitivities almost match the lower boundary values from MIL-F-83300 and, consequently, they are well below the upper limits for N_{δ_r}.

2. Control Lags and Delays

First-order lags in yaw response to the pilot's pedal inputs having time constants of $\tau_\psi = 0.1$, 0.3 and 0.6 were evaluated with and without a 0.1-sec time delay. Two values of N_r (-0.5 and -1) were used with configuration BC1 providing the longitudinal and lateral dynamics. Pilot ratings from these cases are shown in Fig. 53(b). There is a consistent deterioration in rating with lag time constant for both $N_r = -0.5$ and -1. Also, the ΔPR due to the different N_r values remains about the same for all τ_ψ, i.e., the ratings for $N_r = -1$ are consistently about 1 unit better. The addition of the 0.1-sec delay did not change the ratings significantly (Fig. 53(b)). The effect of the lags and the different N_r values can once more be rationalized in terms of the required pilot lead compensation. The phase lags encountered in directional control increase with τ_ψ which in turn increases the requirement for pilot lead compensation and this causes pilot rating to deteriorate. Increasing the damping level, N_r, reduces the phase lags and thereby improves the pilot's rating at a given value of τ_ψ.

The results in Fig. 53(b) show that for a Level 1 value of N_r (-1), first-order lags with time constants of up to $\tau_\psi = 0.3$ are acceptable. The

specification for directional control lags (paragraph 3.2.4) is written in terms of an allowable time within which the initial maximum yaw acceleration must occur ($t_{\ddot{\psi}_{max}} \leq 0.3$ sec). The value of $t_{\ddot{\psi}_{max}}$ for the lag cases evaluated (with and without $d_\psi = 0.1$ sec) with $N_r = -1$ are summarized in the following list.

N_r	τ_ψ	d_ψ	$t_{\ddot{\psi}_{max}}$	PR
-1	0.1	0	0.24	3
		0.1	0.34	2
-1	0.3	0	0.51	3.5
		0.1	0.61	3.8
-1	0.6	0	0.86	4.8
		0.1	0.96	4.7

Without delays the specification excludes $\tau_\psi = 0.3$ ($t_{\ddot{\psi}_{max}} = 0.51 > 0.30$) although this test case was rated satisfactory. Also, the specification permits a 0.1-sec delay which the UARL data indicate is reasonable. However, if $d_\psi = 0.1$ is present a 0.1-sec increment is added to $t_{\ddot{\psi}_{max}}$. As a result, some combinations of d_ψ and τ_ψ which are acceptable to the pilot, e.g., $\tau_\psi = 0.3$ and $d_\psi = 0.1$ are made to appear even more unacceptable in terms of the MIL-F-83300 requirement. That is, $t_{\ddot{\psi}_{max}} = 0.61$ for $\tau_\psi = 0.3$ and $d_\psi = 0.1$ which is twice the allowable $t_{\ddot{\psi}_{max}}$ value (0.30), yet the averaged rating for this case is almost on the satisfactory boundary (PR = 3.8). The control lag specification (paragraph 3.2.4) assumes that the time to maximum angular acceleration limit of 0.3 sec is applicable to pitch, roll and yaw motion. It was shown previously (Section III.A.2) that this requirement is adequate for first-order lags in pitch and roll response. However, it appears that a longer time to maximum angular acceleration is appropriate for yaw.

3. Control-Moment Limits

Yaw control-moment limits were evaluated to determine acceptable values of installed yaw moment for the UARL task. The total yaw control moment was limited, but pitch and roll control moments were effectively unlimited. This evaluation was conducted for two values of N_r (-0.5 and -1 sec) with configuration BC1. The reference value for yaw moment was the average level exceeded 5 percent of the time for the turn subtasks conducted during the turbulence intensity study ($\overline{N}_{c_5} = 0.10$). Note that this value of $\overline{N}_{c_5}$ was appropriate only for configuration BC1. Larger values were recorded for other configurations (see Section III.A.3). Pilot ratings from this study are presented in Fig. 55. For the Level 1 value of N_r (-1) an installed yaw control moment of $N_{c_m} \approx 1.3\ \overline{N}_{c_5}$ was necessary for pilot

acceptance. With $N_r = -0.5$ the required value for N_{c_m} was considerably larger ($\approx 1.6\ \overline{N}_{c_5}$). If nominal lateral maneuvering velocities of 15 ft/sec are assumed, MIL-F-83300 requires that the installed yaw control moment be approximately 0.31 rad/sec^2. This level is well in excess of the 0.13 rad/sec^2 found to be necessary with configuration BC1. However, as mentioned previously, the levels of yaw control moment used varied among the different Level 1 configurations ($\overline{N}_{c_5} = 0.175$ for BC4 and 0.15 for BC5). If it were assumed that for configuration BC4 the required installed $N_{c_m} = 1.3\ \overline{N}_{c_5}$, then N_{c_m} would have to be 0.228 rad/sec^2. This value is also less than the 0.31 rad/sec^2 specified by MIL-F-83300.

4. Effect of Motion on Pilot Ratings for Directional Control

Fixed-base (FB) and moving-base (MB) pilot ratings for directional control are compared in Table XIII. The method of comparison is similar to

TABLE XIII

EFFECT OF MOTION CUES ON PILOT RATINGS FOR DIRECTIONAL CONTROL

Fixed-Base (FB) Rating Level, Number of Ratings	Corresponding Moving-Base Rating		
	Better Than FB Number/Percent of Total	Equal FB Number/Percent of Total	Worse Than FB Number/Percent of Total
Satisfactory, 5	2/40	1/20	2/40
Unsatisfactory, 8	5/62.5	1/12.5	2/25
Unacceptable, 1	1/100	0/0	0/0

that described previously for the height control ratings. The effect of motion on the rating results is also quite similar to those for height control. That is, motion had little effect for satisfactory FB ratings, but improved the ratings for test cases which were more difficult to control

(i.e., those which were rated unsatisfactory and unacceptable with no motion). As for height control, the reason for the improved ratings with motion may have been the improved cues which resulted for heading. This effect would be expected to be more significant for heading control than for longitudinal and lateral control. This is because the visual display provides much better control cues for longitudinal and lateral control than for directional control.

B. Control-Moment Usage

Two of the three investigations related to yaw control-moment usage were based on data obtained with unlimited yaw moment available. The effects of N_r and control lags were evaluated in these two studies. The third study was concerned with the percent time the total yaw control command exceeded the installed moment. Only results for the turn subtask were considered in the control-moment-usage investigations. Very little yaw control moment was used for the other subtasks.

1. Yaw Rate Damping

The effects of N_r on the 5-percent yaw moment exceedance levels are displayed in Fig. 56(a). As was the case for pitch, roll and height control, the 5-percent level for yaw moment decreases with increased damping. Again, it is apparent that with increased levels of stability augmentation, more efficient use is made of the available control moments.

2. Control Lags

The percent-time reference yaw moment levels were exceeded was computed from the moment data for $\tau_\psi = 0.3$ with $N_r = -0.5$ and for $\tau_\psi = 0.3$ and 0.6 with $N_r = -1$. The moment levels exceeded 5 percent of the time are presented in Fig. 56(b). For both levels of N_r there was a significant increase in the 5-percent-exceedance value, N_{c_5}, when a first-order lag of 0.3 sec was added to the control system. A further increase in N_{c_5} was observed for a lag of 0.6 sec. The increase in N_{c_5} is approximately 50 percent for the addition of $\tau_\psi = 0.3$ sec with $N_r = -1$. The results in Fig. 53(b) indicate that this combination yields satisfactory flying qualities. If satisfactory levels of control lag can cause this large an increase in the yaw control-moment usage, it would appear prudent not to change the MIL-F-83300 specification for installed yaw moments. Without control lags the MIL-F-83300 requirements appeared somewhat larger than the yaw control moments found necessary for pilot acceptance in the UARL studies (Sections V.A.3 and III.A.3).

3. Control-Moment Limits

The percent time that total yaw control-moment commands exceeded the installed moment limits are shown in Fig. 56(c). These percentages were computed from yaw control-moment-usage data for the moment limit values evaluated in the study discussed in Section V.A.3 ($N_{c_m} = 1.0\ \overline{N}_{c_5}$, $1.3\ \overline{N}_{c_5}$ and $1.6\ \overline{N}_{c_5}$ where $\overline{N}_{c_5} = 0.10$). As would be expected, the percentages decreased as the installed yaw control moment increased. Also, these results show that the yaw control-moment level which was acceptable to the pilots, $N_{c_m} = 1.3\ \overline{N}_{c_5}$, was exceeded 5 percent of the time. Recall that the reference, $\overline{N}_{c_5} = 0.10$, was the averaged 5-percent exceedance moment level for all the data measured during the turn subtask in the turbulence study (Section III.A.1), when essentially unlimited control moment was available. The larger 5-percent level from the yaw limit study, $N_{c_m} = 0.13$, may have resulted from the pilot's tendency to hold in large pedal inputs which exceeded the yaw control-moment limits. This was done in an attempt to command increased yaw control moment. For unlimited yaw control moments available the aircraft responded to these large inputs and the pilot did not hold the pedal command as long.

SECTION VI

SUMMARY OF PRINCIPAL RESULTS AND RECOMMENDATIONS FOR FURTHER RESEARCH

A. Flying Qualities Results Pertaining to the Development of MIL-F-83300

1. Longitudinal and Lateral Control

a. Turbulence Effects

The Level 1 requirement for V/STOL pitch, roll and yaw dynamic response (paragraph 3.2.2) appears to provide aircraft dynamics which remain quite controllable for nominal increases in turbulence intensity. Pitch and roll control sensitivities selected by the pilots at the largest turbulence intensities considered ($\sigma_{u_g} = \sigma_{v_g} \approx 8.2$ ft/sec) remained well within the specification boundaries (paragraph 3.2.3.2) and were much closer to the minimum required levels than to the maximum limit. These results and previous UARL experience would indicate that the upper control sensitivity limits would result in aircraft response which might be difficult to control.

b. Control Lags and Delays

The specification for control lags (paragraph 3.2.4) adequately separated unsatisfactory levels of first-order lags in pitch and roll control response from those which did not significantly degrade pilot ratings for Level 1 configurations (i.e., those that met the Level 1 requirement of paragraph 3.2.2 of MIL-F-83300) evaluated in this study. Pilot ratings also show that permitting a 0.1-sec delay in control response, as the specification does, is reasonable. However, limited results for second-order control lags indicate that the specification may not be sufficiently general to apply to second-order control lags. Control sensitivities selected in this study were generally near, and sometimes below, the minimum MIL-F-83300 boundary. It may be appropriate to lower both the minimum and maximum control sensitivity boundaries somewhat.

c. Control-Moment Requirements

The pitch and roll control-moment requirements from MIL-F-83300 (paragraph 3.2.3.1) generally equalled or exceeded those levels found to be necessary in this program for the Level 1 and 2 configurations considered (without control system lags or delays). Also, the specified control moments were generally not excessive. The addition of control system lags and delays increased the control moments found to be necessary for satisfactory ratings, and the wording of paragraph 3.2.3.1 also provides for this effect. However, the specification control-moment requirements may be excessive for control systems with acceptable lags.

d. Control Moments Through Stored Energy

It appears that rotor-propulsion system angular momentum can be used to offset, to some extent, deficiencies in the installed control moments. However, additional research is required before consideration can be given to accounting for its effects in MIL-F-83300.

e. Inter-Axis Motion Coupling

Pitch and roll rate coupling and control coupling can cause an appreciable deterioration in V/STOL flying qualities. Results from this study indicate that rate coupling levels must be no larger than $M_p = 1$ and/or $L_q = -1$ per sec for satisfactory flying qualities. Control coupling ratios should be limited to $M_{\delta a}/L_{\delta a}$ and/or $L_{\delta e}/M_{\delta e}$ less than about 0.25. The control sensitivity specification does not have to be changed to account for motion coupling.

f. Independent Thrust-Vector Control

Thrust-vector control independent of aircraft attitude can be an acceptable substitute for conventional attitude control when properly implemented. For large aircraft with Level 1 pitch and roll dynamics, the use of ITVC should provide satisfactory flying qualities while enabling the pilot to avoid pitch (or roll) attitudes that could lead to ground strikes. For aircraft having large drag parameters, ITVC would enable pilots to control position without the large attitude changes and trim attitude angles that result for such aircraft with conventional position control through attitude. However, position control for such aircraft would remain moderately difficult, even with ITVC.

g. Rate-Command/Attitude-Hold Control

It appears that rate-command/attitude-hold control as mechanized in this study provides no particular benefits over conventional rate and attitude stabilized control systems for hover and low-speed flight operations. Also, the dynamic response portion of MIL-F-83300 (paragraph 3.2.2.1) does not define characteristics which provide satisfactory dynamic response for rate-command/attitude-hold control systems. However, the specification for control sensitivities (paragraph 3.2.3.2) does encompass those sensitivities needed with rate-command/attitude-hold control.

2. Height Control

a. Z_w and Thrust-to-Weight Ratio

There is a definite interaction between Z_w, T/W and height control flying qualities for T/W less than about 1.05. This result supports to

some extent the method used in MIL-F-83300 to specify Z_w and T/W (paragraph 3.2.5.1). However, MIL-F-83300 permits $Z_w = 0$ for $T/W \geq 1.10$, but results from the UARL program indicate that a minimum $Z_w = -0.25$ to -0.35 is necessary for Level 1 height control. Also, if this Z_w level is present, it would appear that the T/W boundary separating Level 1 and 2 flying qualities could be reduced. Height control sensitivities from this study were within the specification limits (paragraph 3.2.5.3) but were much closer to the minimum boundary than the maximum.

b. Lags and Delays in Thrust Response

The specification for lags and delays in thrust response (paragraph 3.2.5.2) appears reasonable in view of the UARL results. However, it does not account for the ability of increased Z_w to compensate for lag effects.

c. Incremental Thrust Through Stored Energy

Results indicate that the effects of incremental thrust through stored energy can alleviate, to an extent, deficiencies in installed thrust. However, these data are presently too limited to permit consideration of changes in MIL-F-83300 to account for its effects.

3. Directional Control

a. Yaw Rate Damping

Results from this program indicate that the directional damping paragraph in MIL-F-83300 (3.2.2.2) which requires $N_r = -1$ for Level 1 flying qualities is reasonable. Also, the pilot-selected yaw control sensitivities, N_{δ_r}, almost matched the lower boundary values from paragraph 3.2.3.2.

b. Control Lags and Delays

The control lag specification (paragraph 3.2.4) should be modified to permit a longer time to attain maximum yaw acceleration, $t_{\ddot{\psi}_{max}}$. For acceptable control lags and delays, $t_{\ddot{\psi}_{max}}$ was as much as twice the MIL-F-83300 limit (0.3 sec).

c. Yaw Control-Moment Requirements

The specification for yaw control moment (paragraph 3.2.3.1) requires control moments which are without exception larger than those found to be necessary in this program. However, the yaw control-moment requirements of the specification do not appear to be excessive.

B. Control-Moment Usage

1. Longitudinal and Lateral Control

Pitch and roll control-moment usage increases with turbulence intensity. However, the increase does not scale directly with turbulence intensity, apparently because there is a minimum level of control-moment usage which exists without turbulence due to the moment requirement for task performance, trim of the mean wind, and inadvertent pilot inputs. Speed stability is the aircraft/control system configuration parameter having the greatest effect on control-moment usage. The change in the 5-percent-exceedance moment levels for a threefold increase in speed stability was much greater than that for a factor of four change in drag parameter. Drag parameter may not have to be a consideration in the development of control-moment criteria. The change in control-moment usage with speed stability was also greater than that which resulted when aircraft pitch and roll dynamics deteriorated (accomplished by reducing the level of stability augmentation) from Level 1 to Level 3. Control-moment usage increased with decreasing level of augmentation which confirms that stability augmentation systems make more efficient use of control moment than does the pilot. Control lags had little effect on pitch and roll control-moment usage, and it may be possible to eliminate them from consideration in the development of control-moment specifications. Pitch and roll control coupling also had little effect on control-moment usage, but usage did increase with pitch and roll rate coupling.

The low-speed flight task required of a V/STOL aircraft has been shown to have an appreciable effect on control-moment usage. The 5-percent-exceedance moment levels for the quick stop are as much as 1.5 times as large as those for hover. The expected task must be accounted for when defining requirements for installed control moment. Also, the installed total moment for pitch plus roll control must be sufficient to account for simultaneous control usage by the pilot. It cannot be assumed that pilots make independent pitch and roll control inputs.

Finally, it appears that specifying levels for installed control moment by requiring that they equal those levels which the pilot would be expected to exceed 5 percent of the time is not acceptable. However, it may be that acceptable installed control-moment levels would correlate better with those levels exceeded a smaller percent of the time.

2. Height Control

Thrust usage decreased with increased levels of height velocity damping. Lags in the thrust response increased thrust usage; this contrasts with the effect of lags on pitch and roll control-moment usage. With satisfactory levels of Z_W, installed thrust-to-weight ratios of 1.05 were seldom exceeded and T/W = 1.10 was never exceeded.

3. Directional Control

Yaw control-moment usage decreased with increased yaw rate damping for the values of yaw rate damping tested, i.e., $|N_r| < 1.0$. Moment usage increased with lags in the yaw response to control inputs, however.

C. Effects of Flight Simulator Motion Cues on Pilot Ratings

For longitudinal and lateral control the addition of flight simulator motion resulted in poorer pilot ratings than those assigned when the same test cases were evaluated without motion. This trend was evident for all cases, regardless of their flying qualities, i.e., whether or not they had been rated satisfactory, unsatisfactory or unacceptable without motion. For both height and yaw control, however, the addition of motion generally resulted in improved ratings for test cases which were rated unsatisfactory or unacceptable without motion. For cases rated satisfactory fixed base, the addition of simulator motion appeared to have little effect on the pilot's rating of height or directional flying qualities.

D. Recommendations for Further Research

It is recommended that the following research be conducted to obtain information pertinent to the further development of MIL-F-83300.

(1) Additional fixed- and moving-base flight simulator studies of control-power usage should be conducted. In these studies, the significance of aircraft, control system and task parameters would be further evaluated and the control-power specification would be tested in more detail.

(2) The ability of rotor-propulsion system stored energy to compensate for limits in installed control power should be investigated in more detail.

(3) Additional unconventional control systems such as on-off (bang-bang) control and velocity-vector (TAGS) control should be evaluated to determine their attributes. Modifications to MIL-F-83300 to extend its coverage to these systems must be explored. Independent thrust-vector control should also be examined in more detail; it appears to be a promising concept, but was only given limited study in this program.

LEVEL	1			2		·3
BASIC CONF.	BC1	BC4	BC5	BC2	BC6	SC3
SYMBOL	○	□	△	◇	◺	◖

LEVEL RELATES FLYING QUALITIES TO PITCH AND ROLL DYNAMIC RESPONSE REQUIREMENTS IN PARAGRAPH 3.2.2 OF MIL–F–83300 (REF. 1)

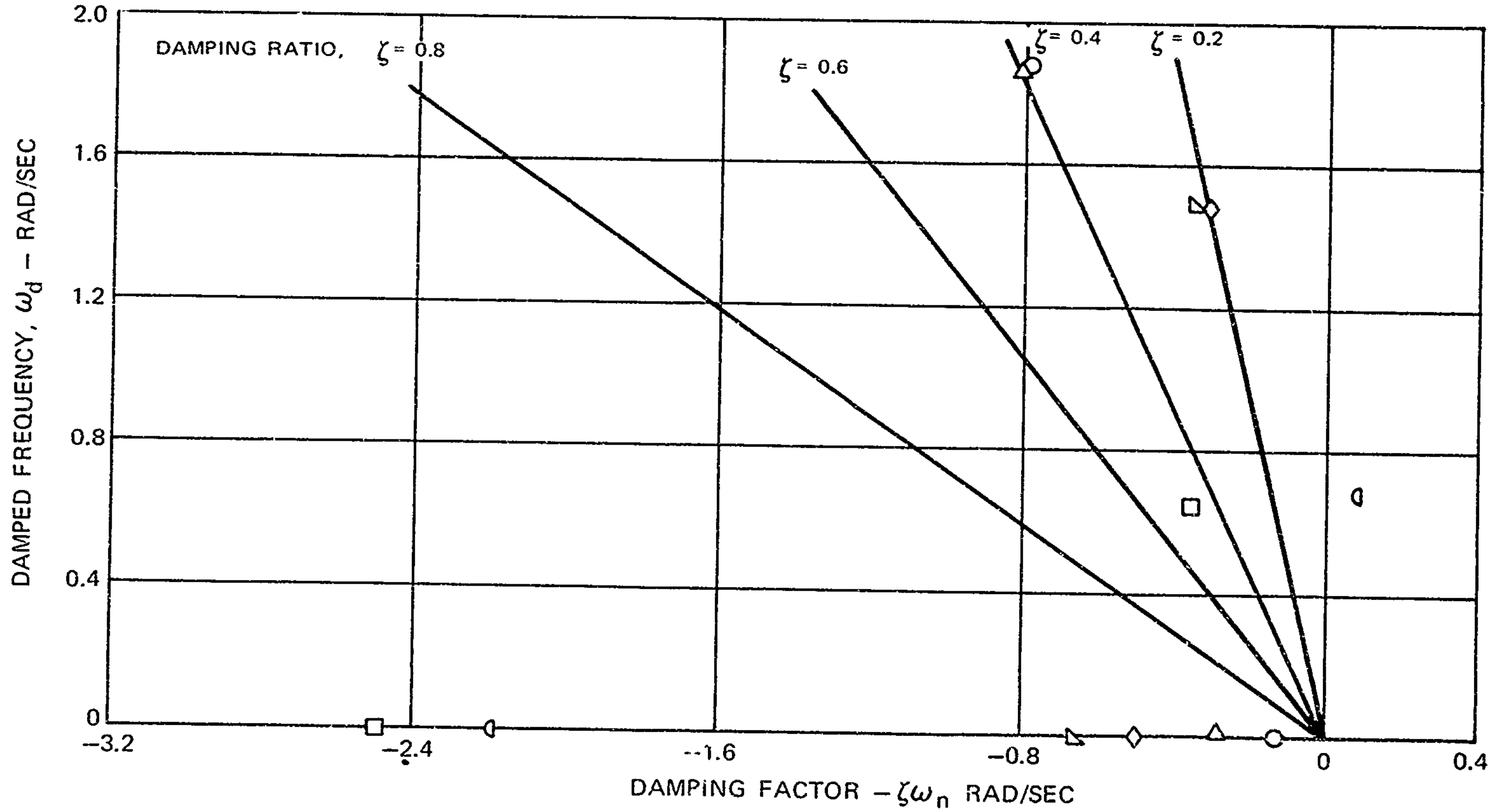


Figure 1. Root Locations for UARL Basic Configurations

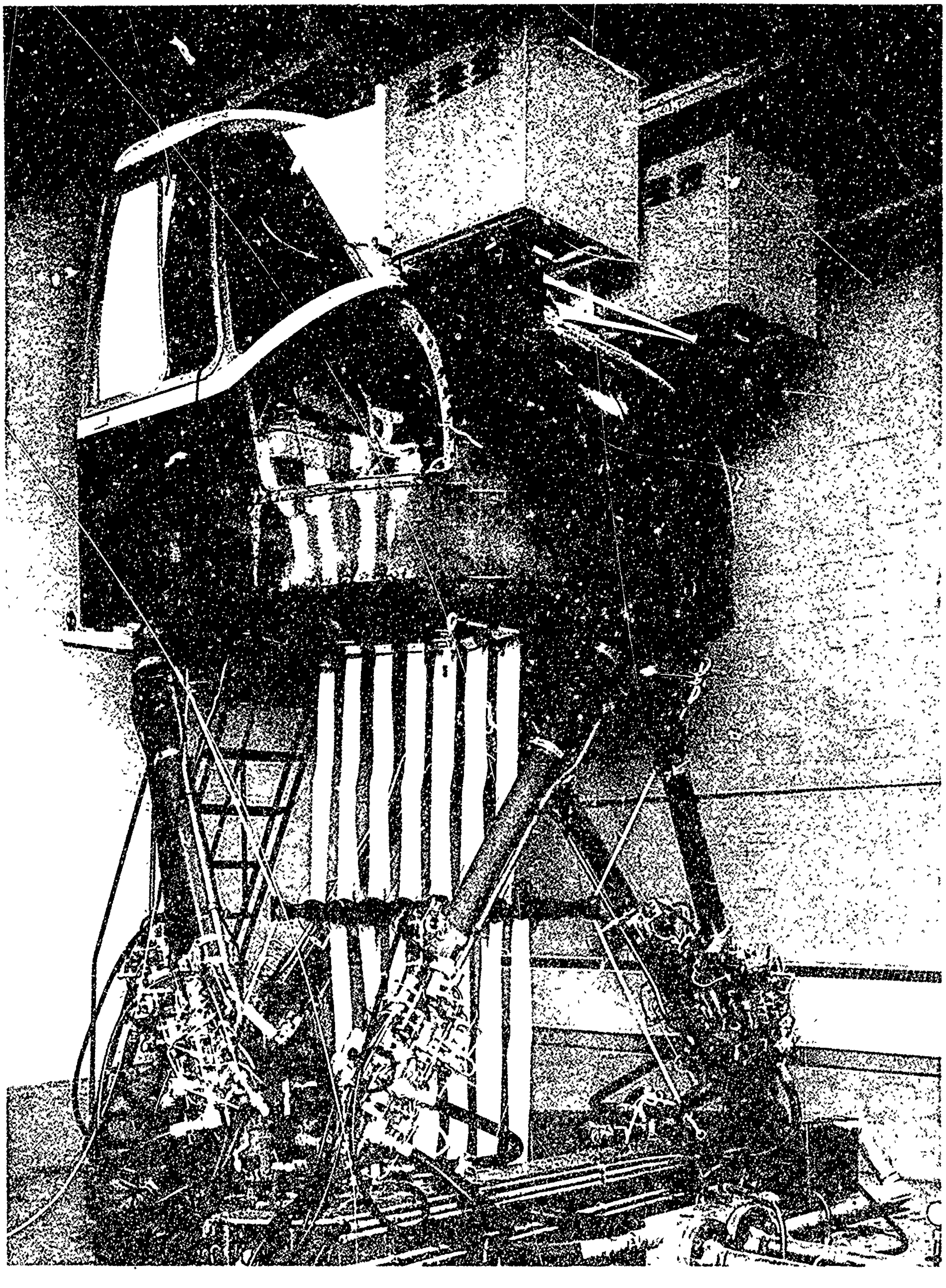


Figure 2. United Aircraft Corporation V/STOL Aircraft Flight Simulator

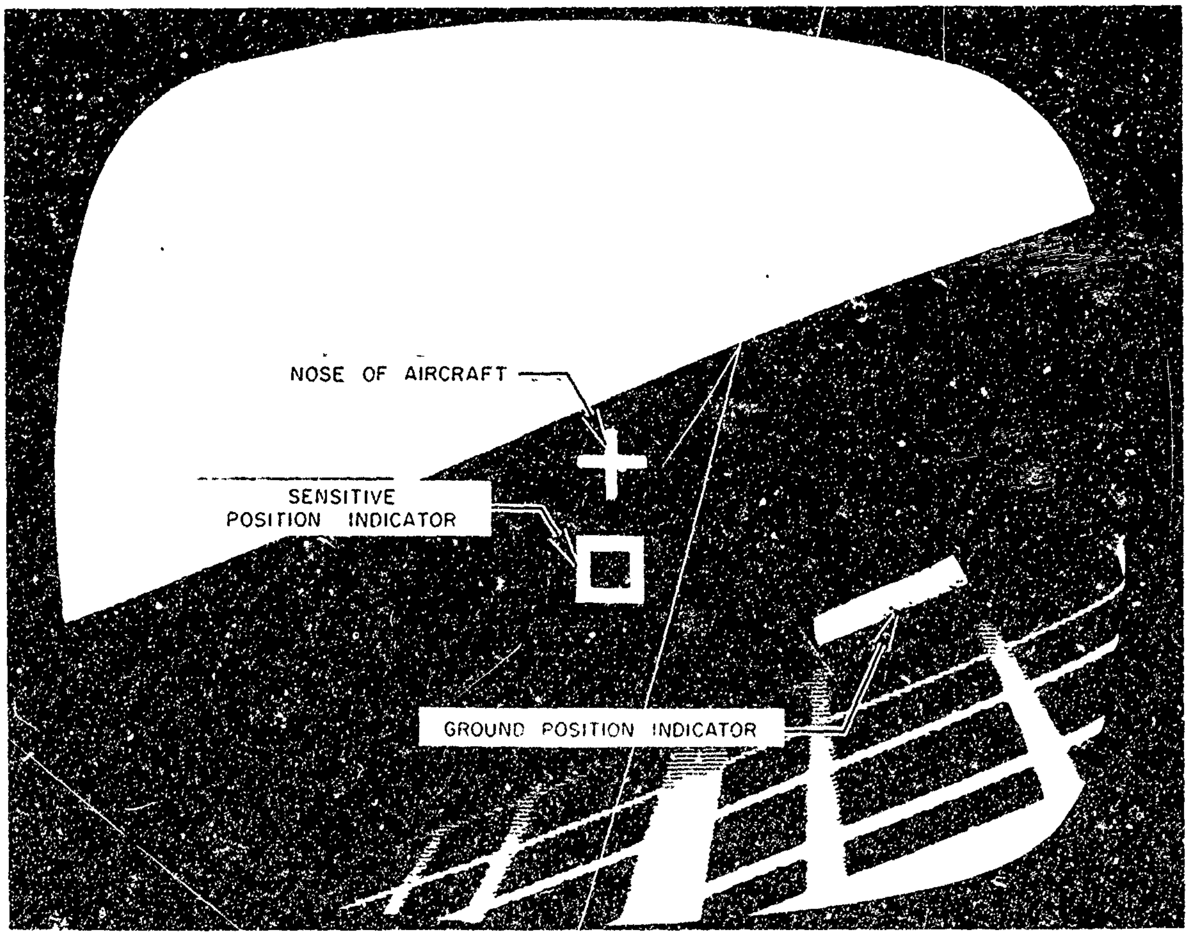


Figure 3. Contact Analog Display for Hovering and Low-Speed Maneuvering Task

SIMULATION	UARL		NORAIR
SIMULATOR MODE	FB	MB	MB
SYMBOL	○	●	■

$\sigma_{u_g} = \sigma_{v_g}$ = 3.4 FT/SEC U_m = 10 KTS FROM NORTH

*SEE NOTE ON LEVEL DESIGNATION SHOWN ON FIG. 1

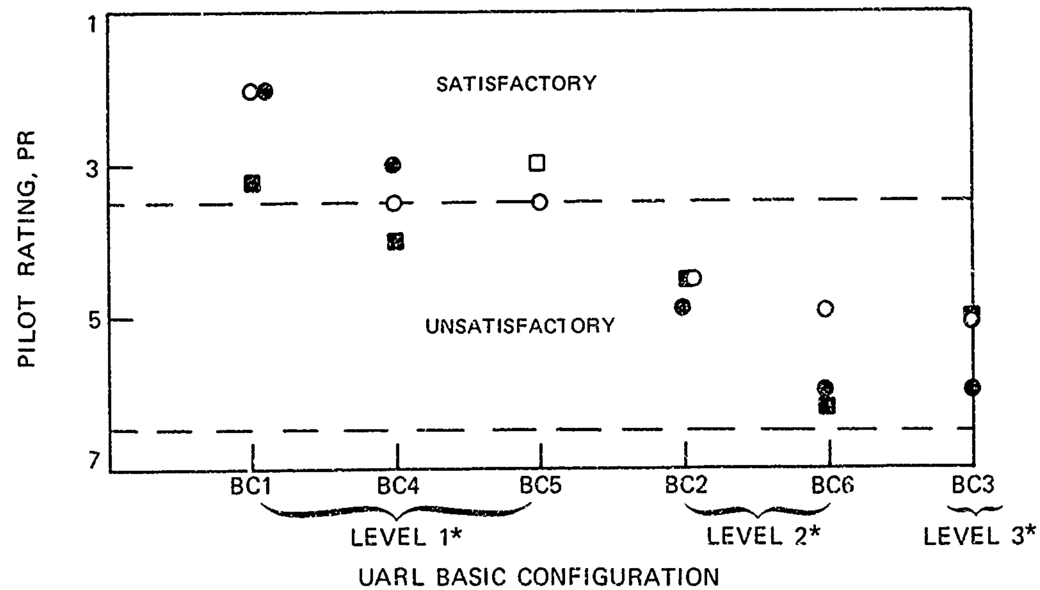


Figure 4. Comparison of Averaged Pilot Ratings from UARL and Norair Simulations for Similar Configurations

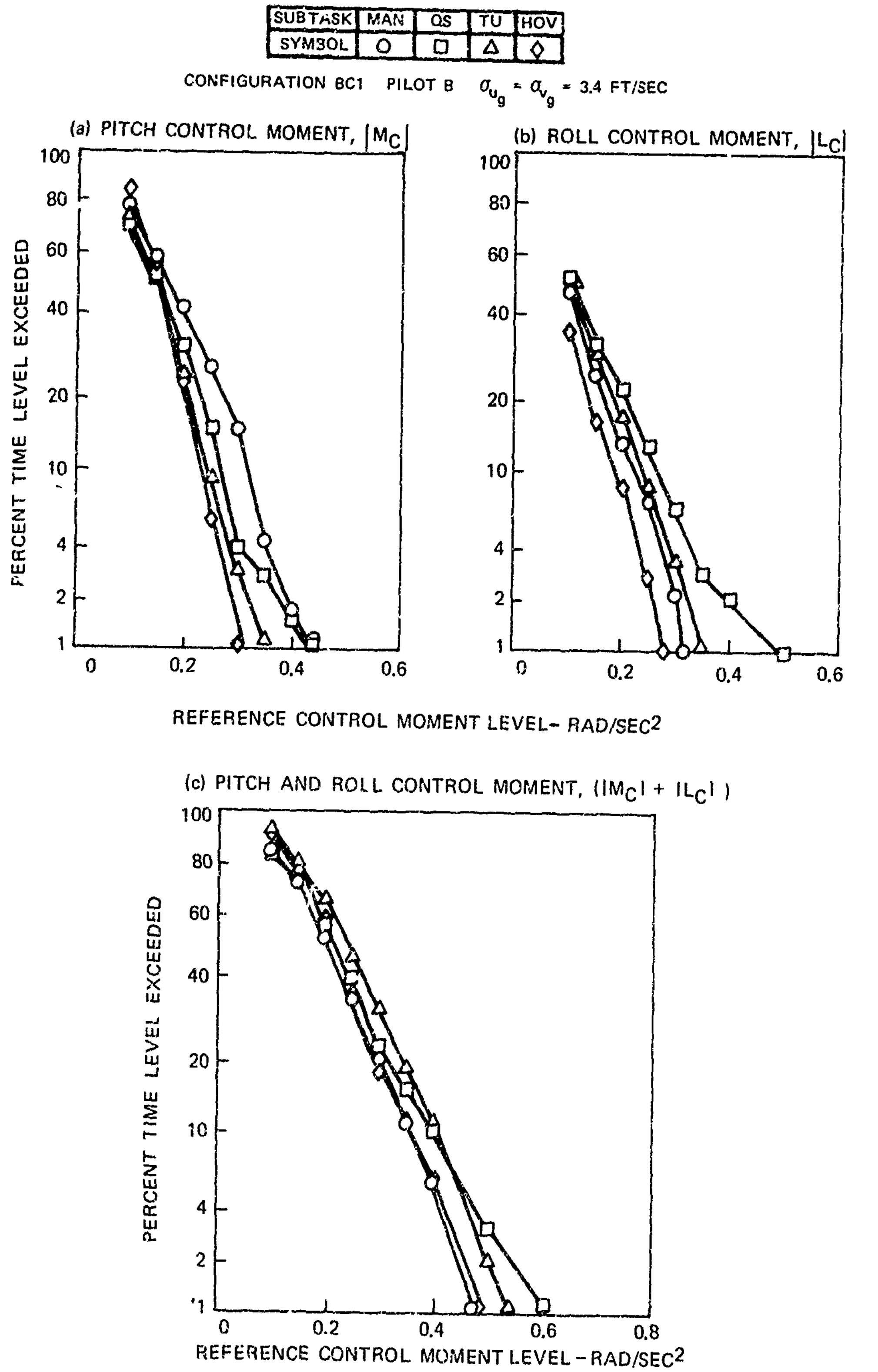


FIGURE 5. Representative Exceedance Plots Showing the Effects of Subtask on Control-Moment Usage

SIMULATOR MODE, PILOT	FIXED, A		FIXED, B		MOVING, B	
CONFIGURATION	BC4	BC1	BC4	BC	BC4	BC1
SYMBOL	○	●	□	■	△	▲

BC1, BC4 LEVEL 1 CONFIGURATIONS $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

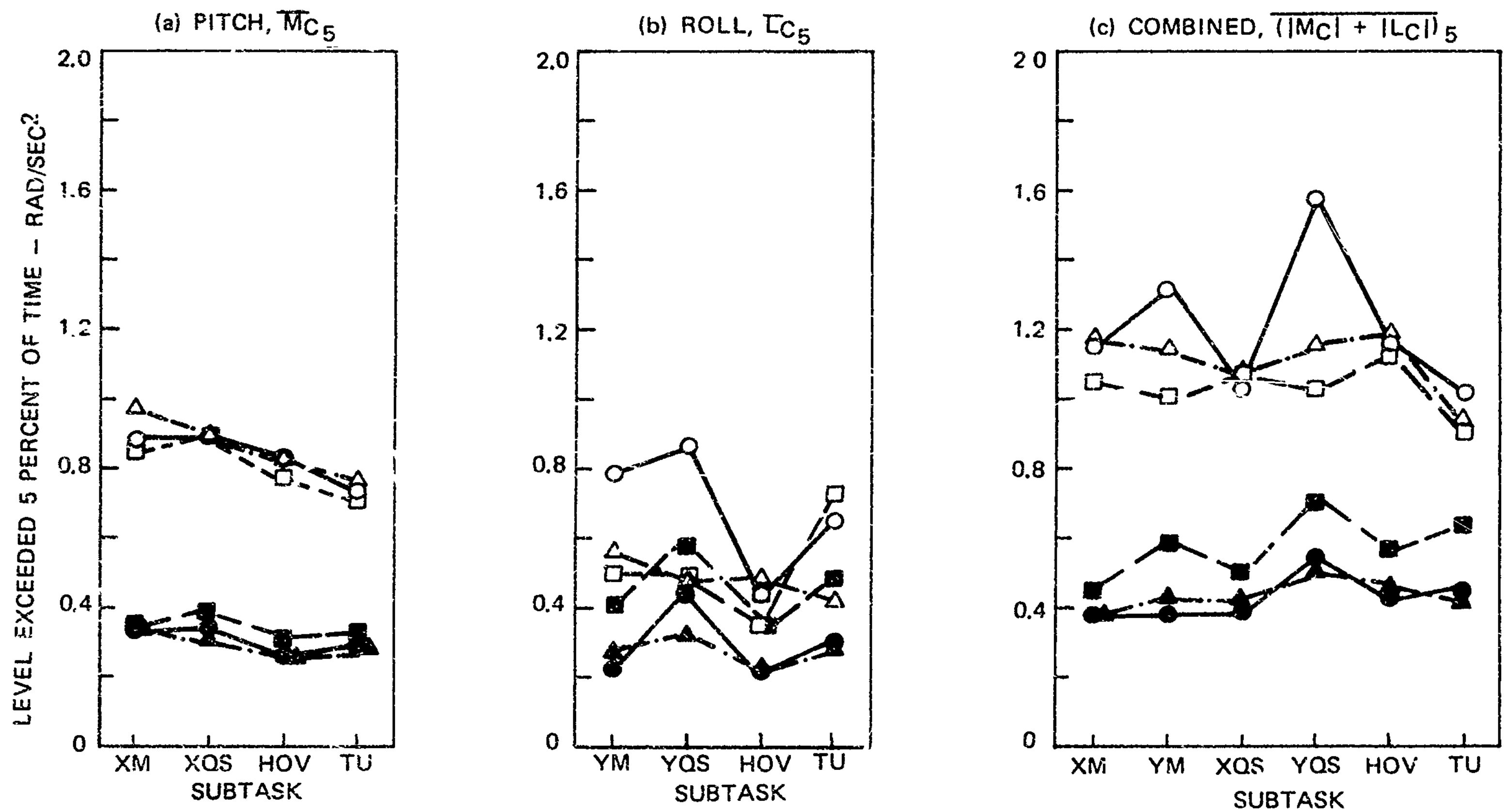


FIGURE 6. Variations in Moment Level Exceeded Five Percent of Time for Two Pilots and Fixed- and Moving-Base Simulator Operation

LEVEL *	1						2				3	
BASIC CONF.	BC1		BC4		BC5		BC2		BC6		BC3	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆	▽	▼	◺	◣

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES

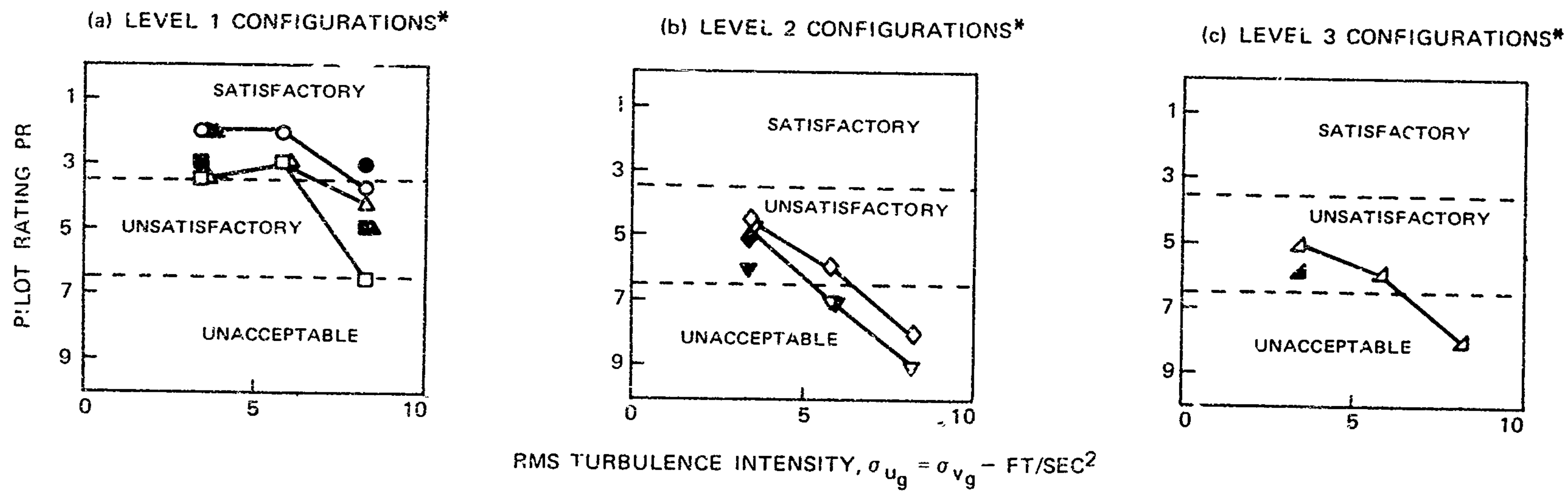


Figure 7. Variation in Pilot Rating with Turbulence Intensity

TURBULENCE INTENSITY INTERVAL	3.4–5.8		5.8–8.2		3.4–8.2	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

* LEVEL APPLIED TO BASIC CONFIGURATIONS ONLY DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

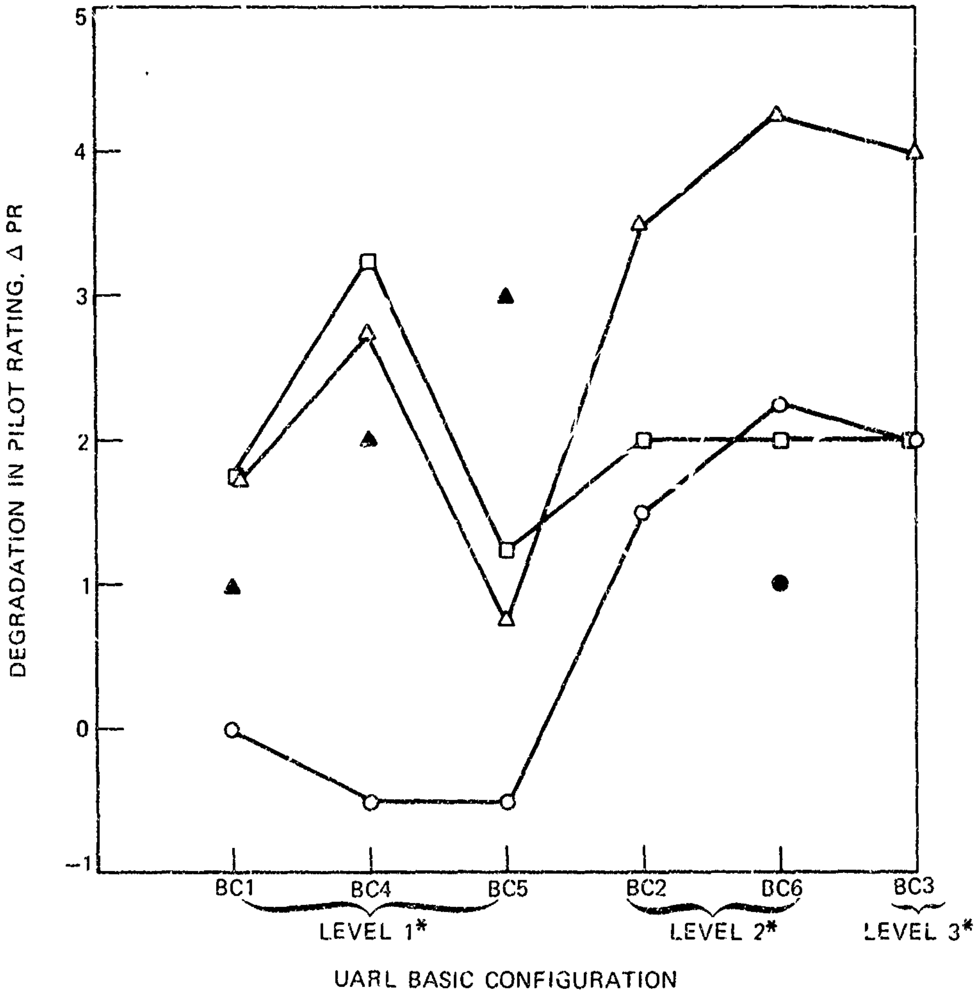


Figure 8. Effect of Pitch and Roll Dynamics Level on Degradation in Pilot Rating with Turbulence Intensity

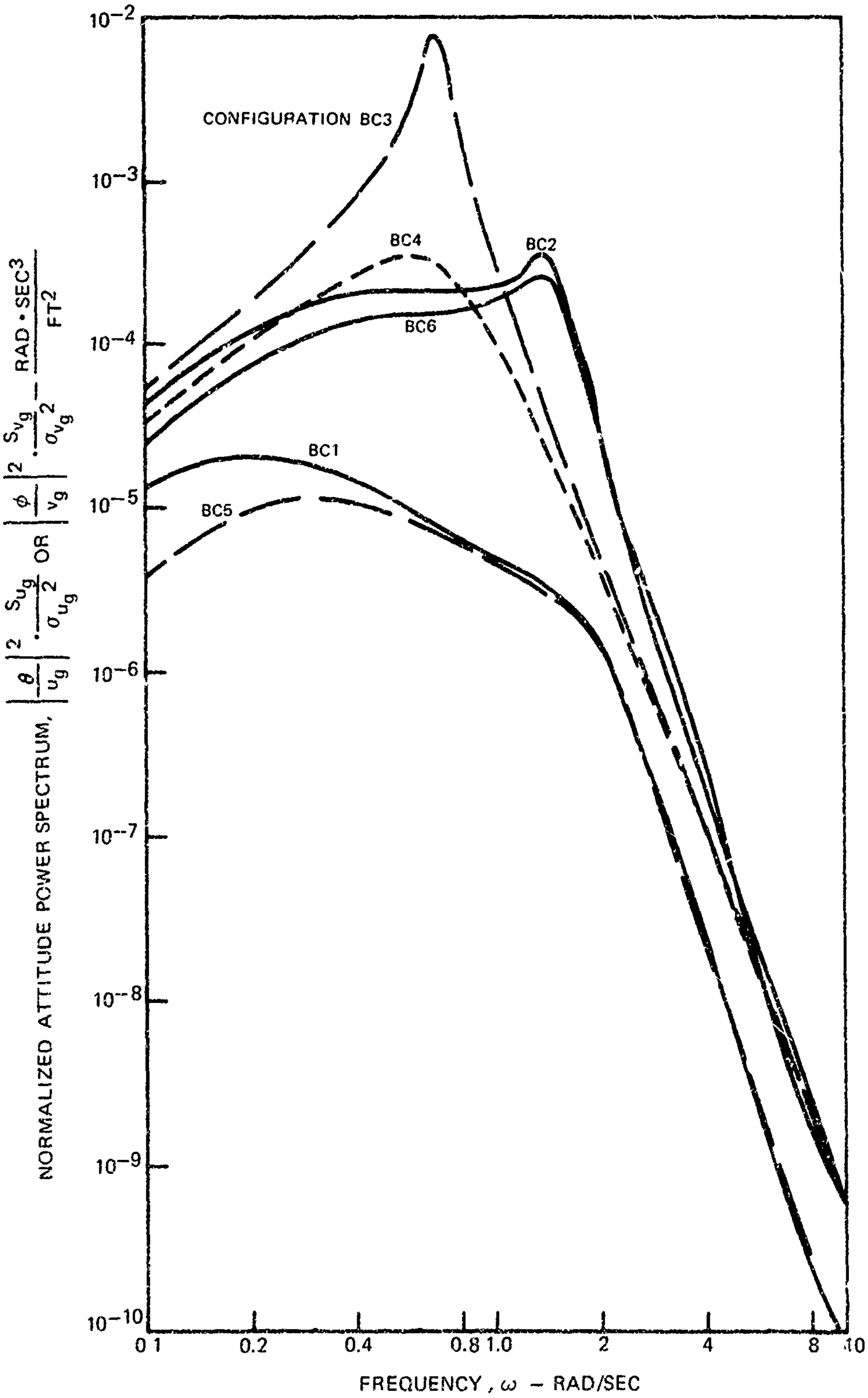


Figure 9. Power Spectrum of Open-Loop Attitude Response to Simulated Turbulence for Basic Configurations

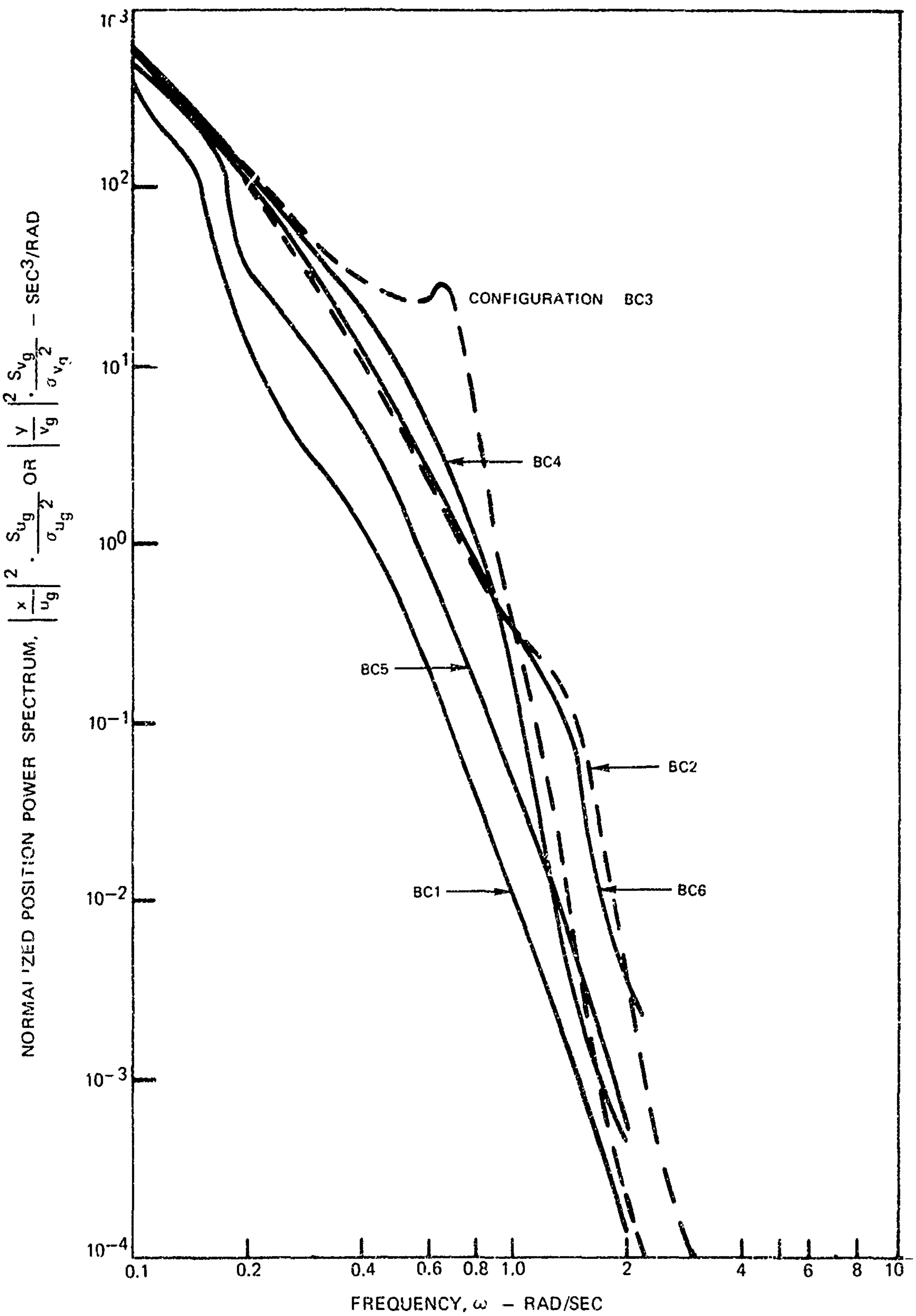


Figure 10. Power Spectrum of Open-Loop Position Response to Simulated Turbulence for Basic Configurations

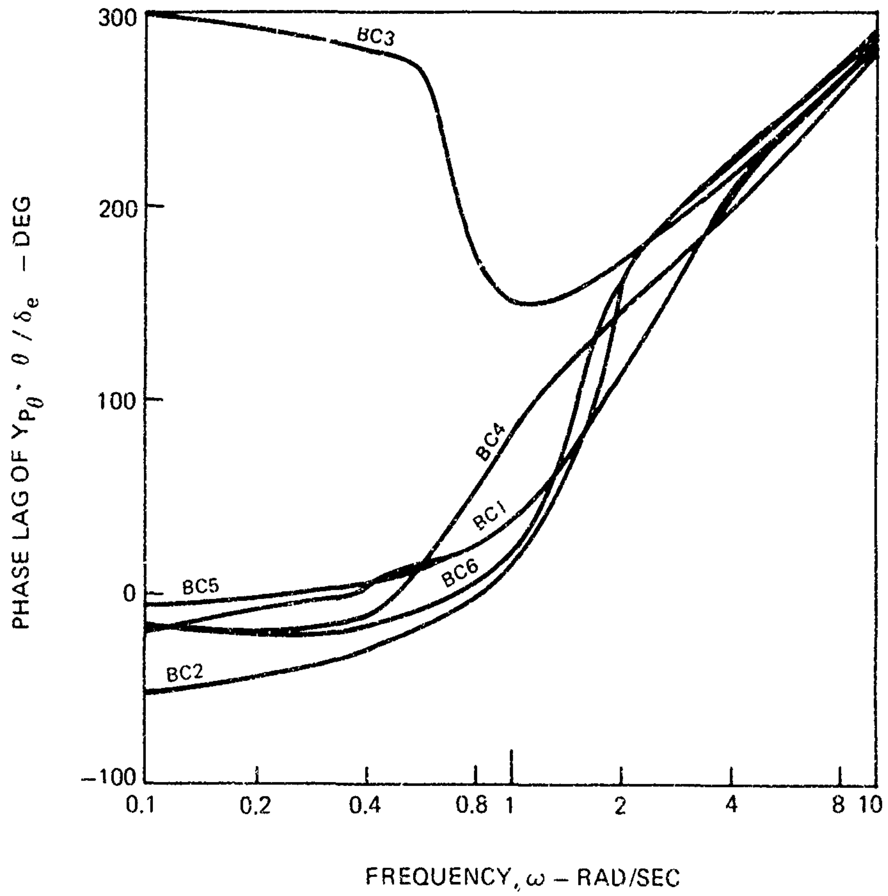


Figure 11. Phase Lag of Pilot-Pitch (Roll) Open-Loop Dynamics for UARL Basic Configurations

LEVEL*	1						2				3	
BASIC CONF.	BC1		BC4		BC5		BC2		BC6		BC3	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆	▽	▼	⊿	◢

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

DASHED LINES SHOW MIL–F–83300 BOUNDARIES FOR ACCEPTABLE M_{δ_e}. BOUNDARIES BASED ON SPECIFIED MINIMUM AND MAXIMUM ATTITUDE RESPONSE (NORMALIZED WITH CONTROL COMMAND MAGNITUDE) ONE SECOND AFTER CONTROL INPUT

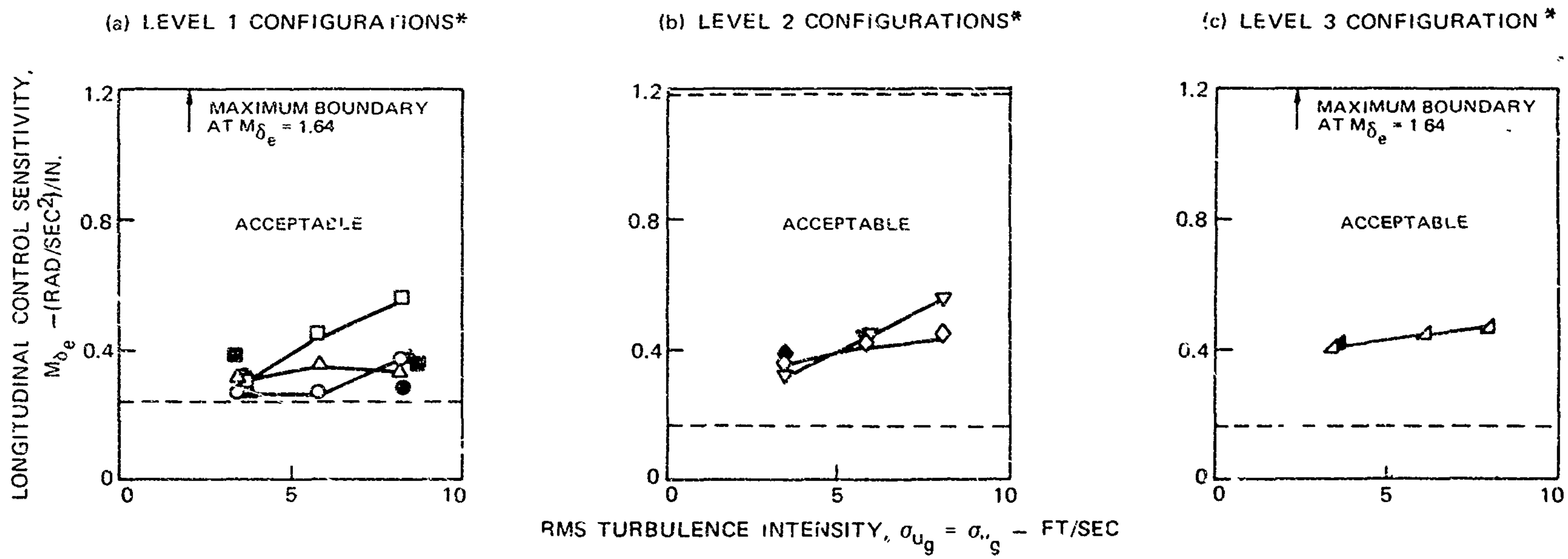


Figure 12. Longitudinal Control Sensitivities from Turbulence Study

LEVEL *	1						2				3	
BASIC CONF.	BC1		BC4		BC5		BC2		BC6		BC3	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆	▽	▼	◿	◢

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

DASHED LINES SHOW MIL–F–83300 BOUNDARIES FOR ACCEPTABLE L_{δ_a}. SEE NOTE ON FIG. 12.

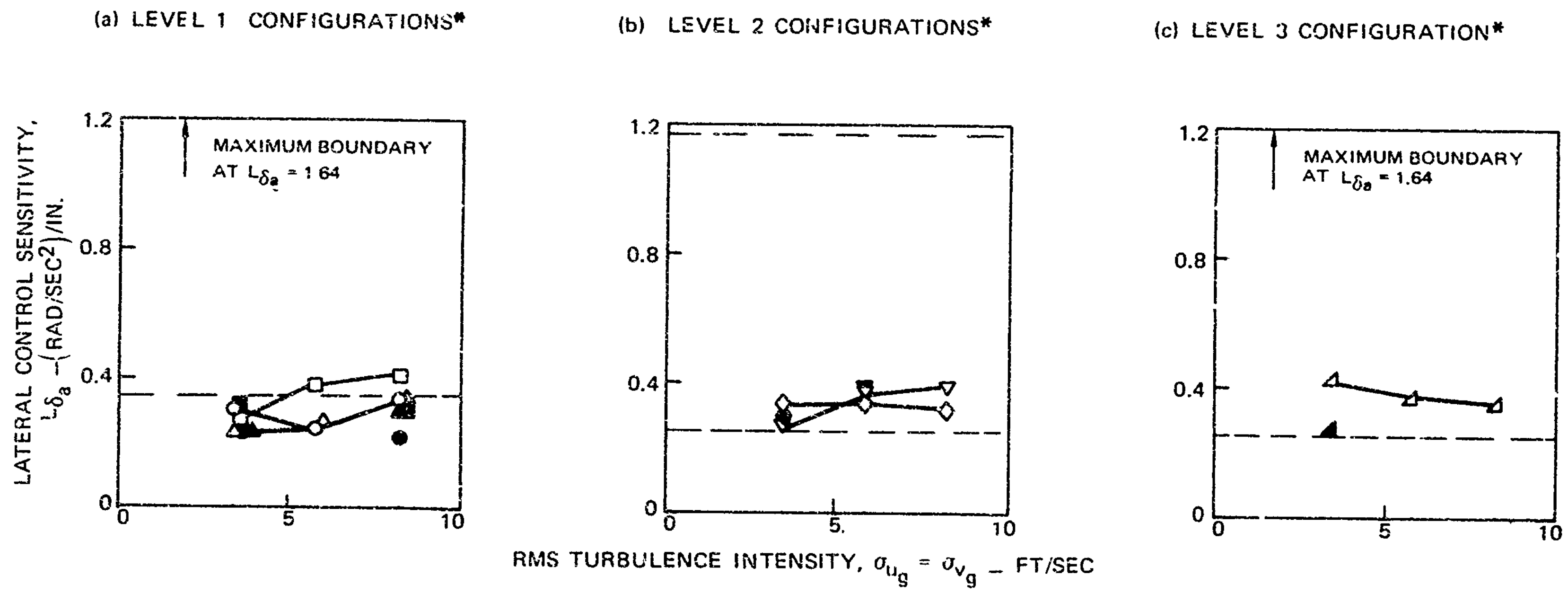


Figure 13. Lateral Control Sensitivities from Turbulence Study

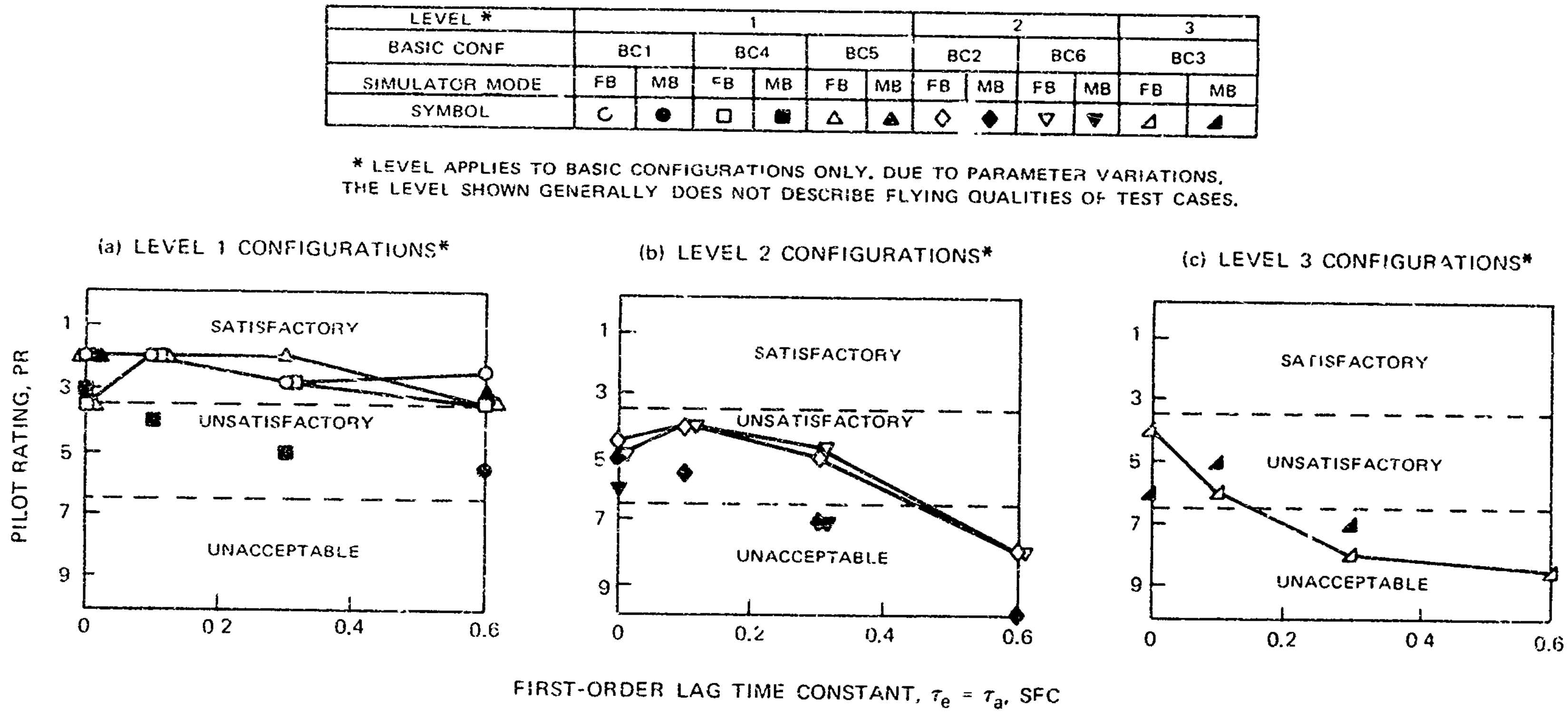


Figure 14. Variation in Pilot Rating with Time Constant of First-Order Lag in Control Response

LAG TIME CONSTANT INTERVAL	0–0.3		0.3–0.6		0–0.6	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

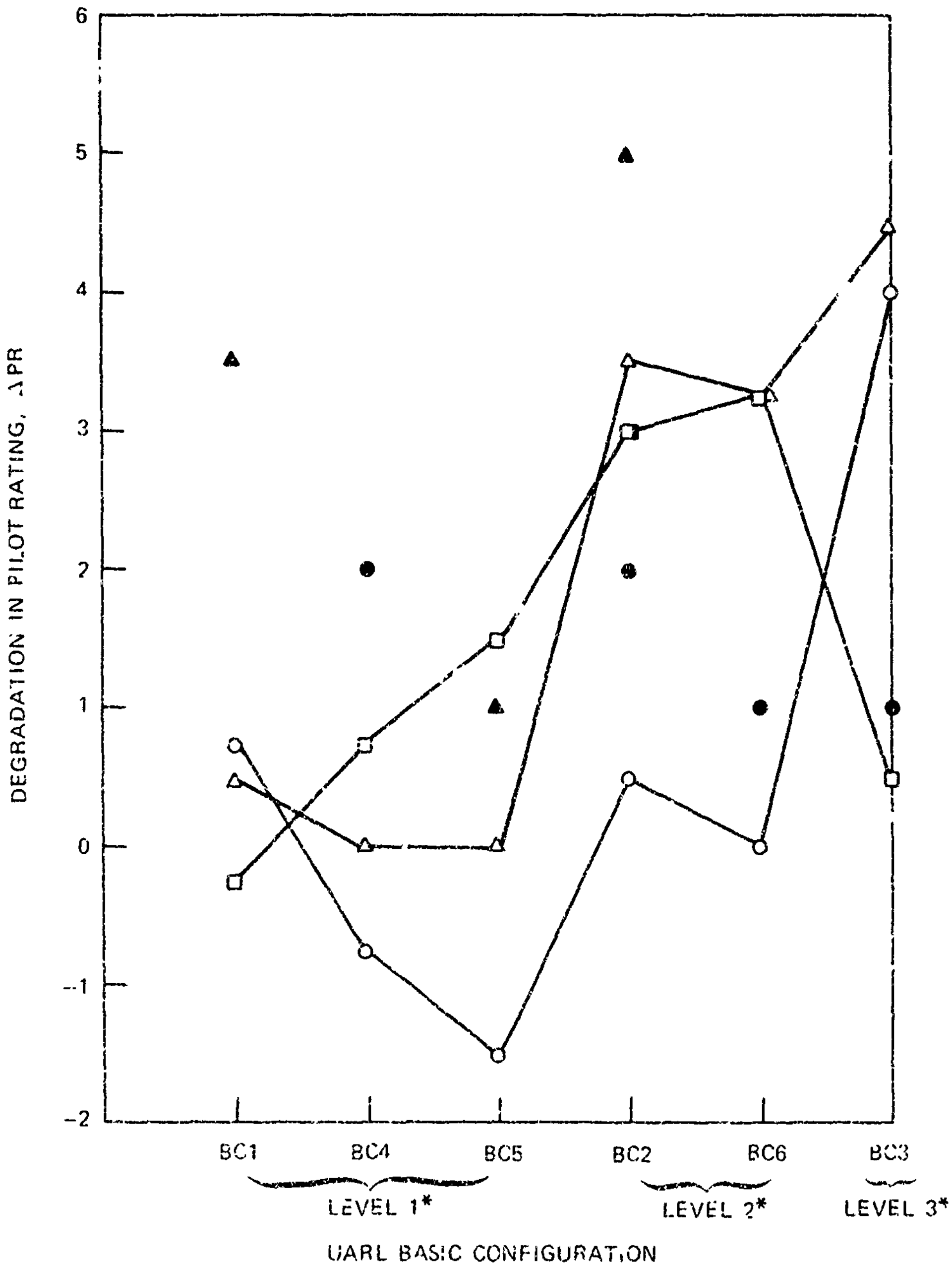


Figure 15. Effect of Pitch and Roll Dynamics Level on Degradation in Pilot Rating with First-Order Lag Time Constant

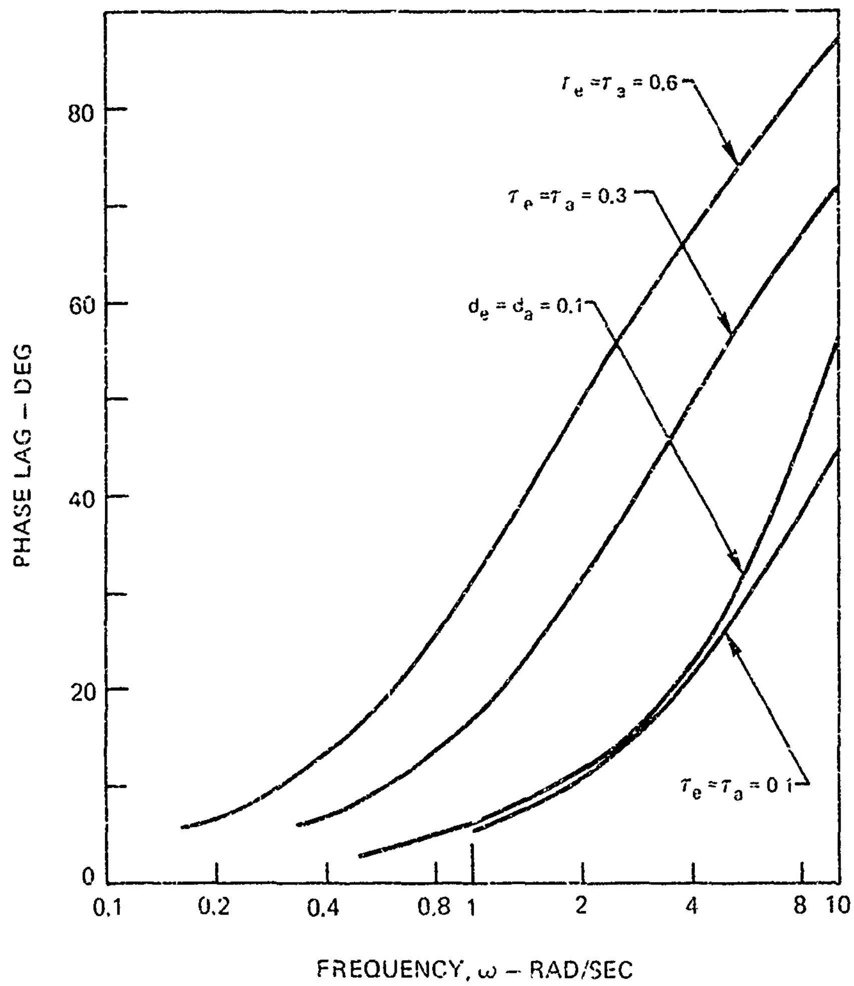


Figure 16. Phase Lags from First-Order Lags and Delays

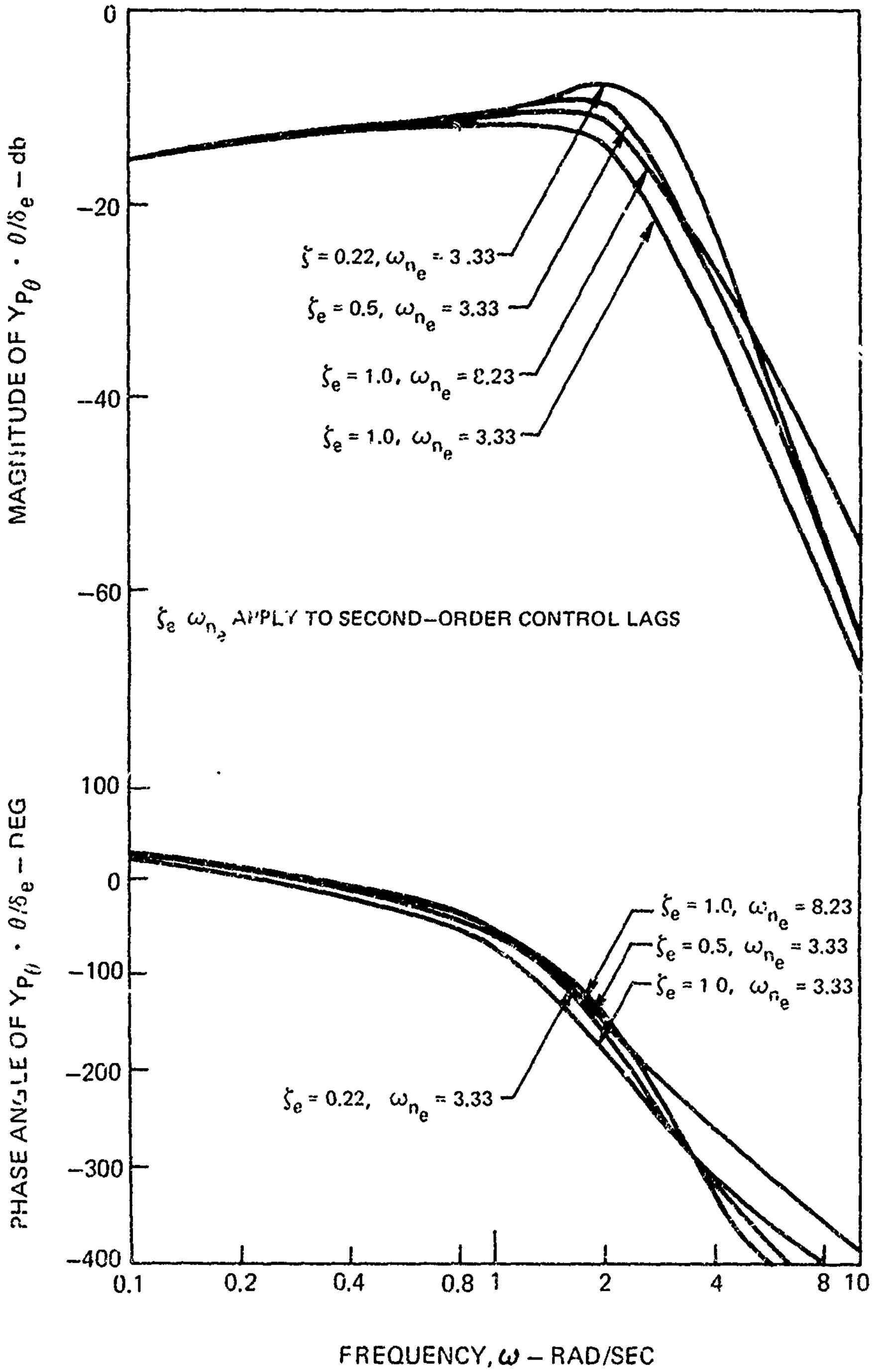


Figure 17. Magnitude and Phase Characteristics for Pilot-Pitch (Roll) Open-Loop Dynamics with Second-Order Control Lags

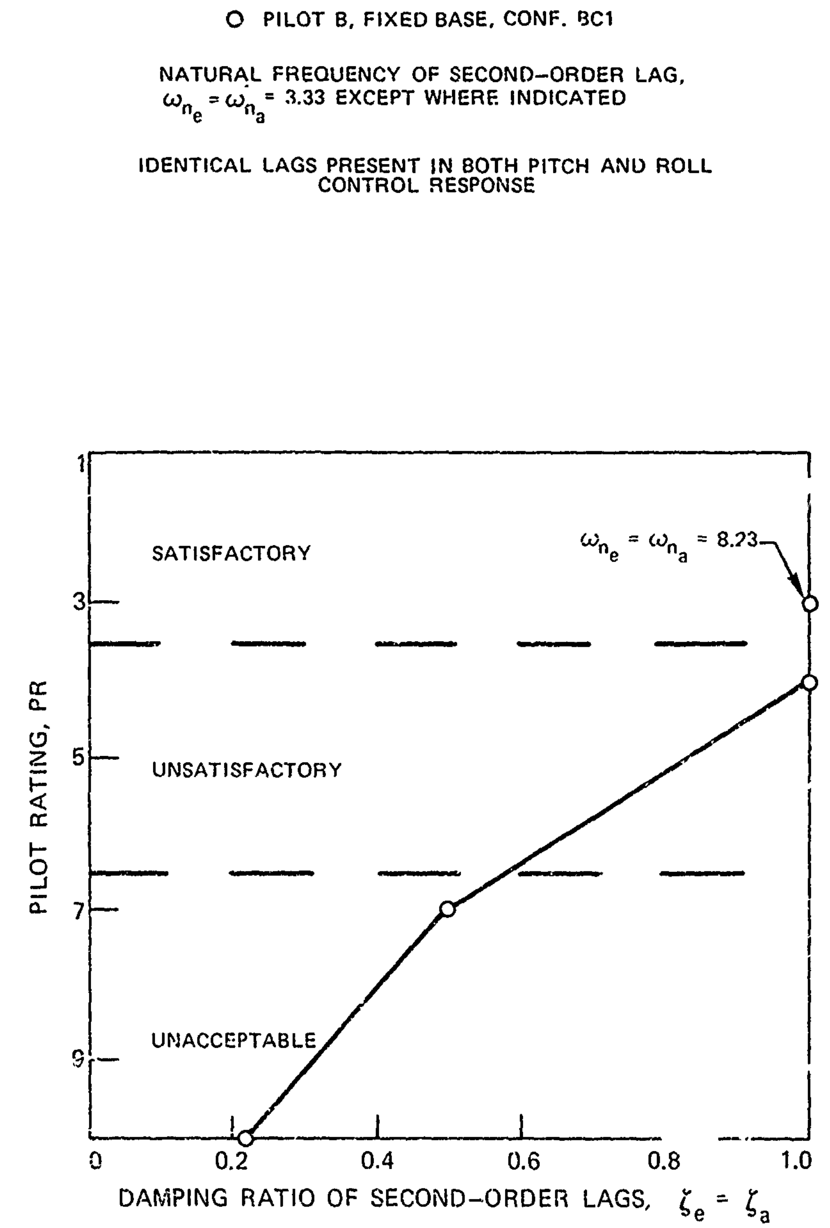


Figure 18. Pilot Ratings for Second-Order Lags in Pitch and Roll Control Response

LEVEL *	1						2				3	
BASIC CONF.	BC1		BC4		BC5		BC2		BC6		BC3	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆	▽	▼	⊿	◢

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

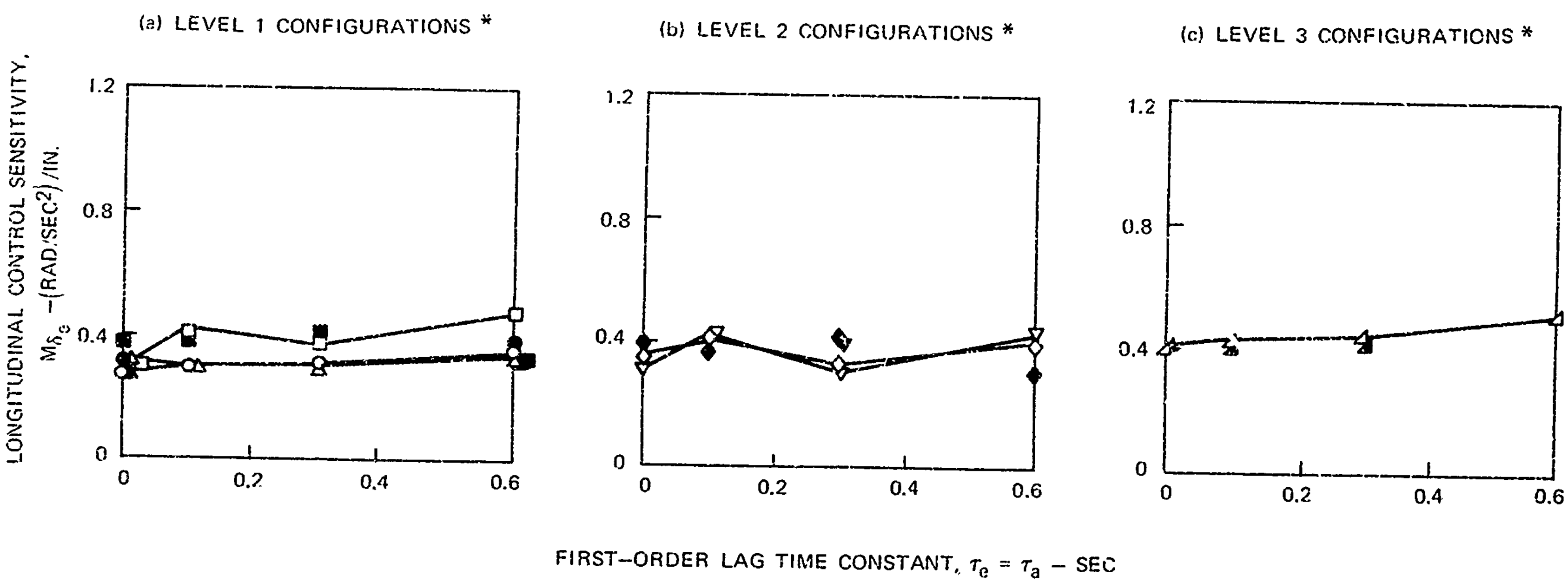


Figure 19. Longitudinal Control Sensitivity Results Showing the Effects of First-Order Control Lag

LEVEL *	1						2				3	
BASIC CONF.	BC1		BC4		BC5		BC2		BC6		BC3	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆	▽	▼	⊿	◢

* LEVEL APPLIES TO BASIC CONFIGURATIONS ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

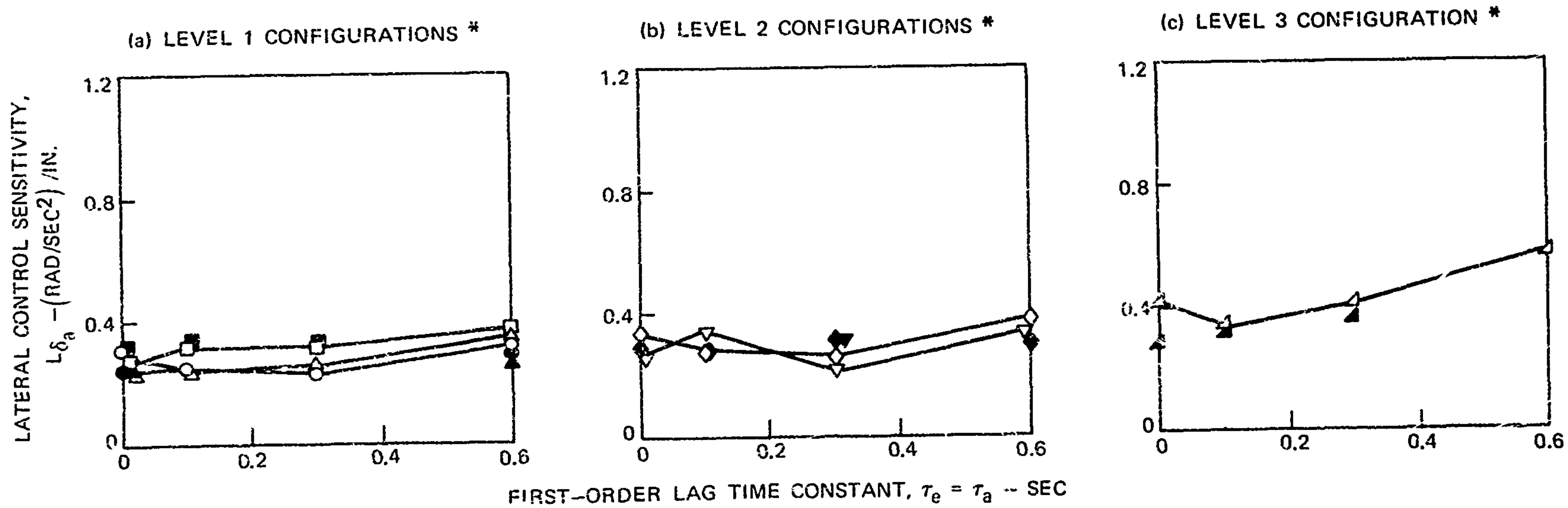


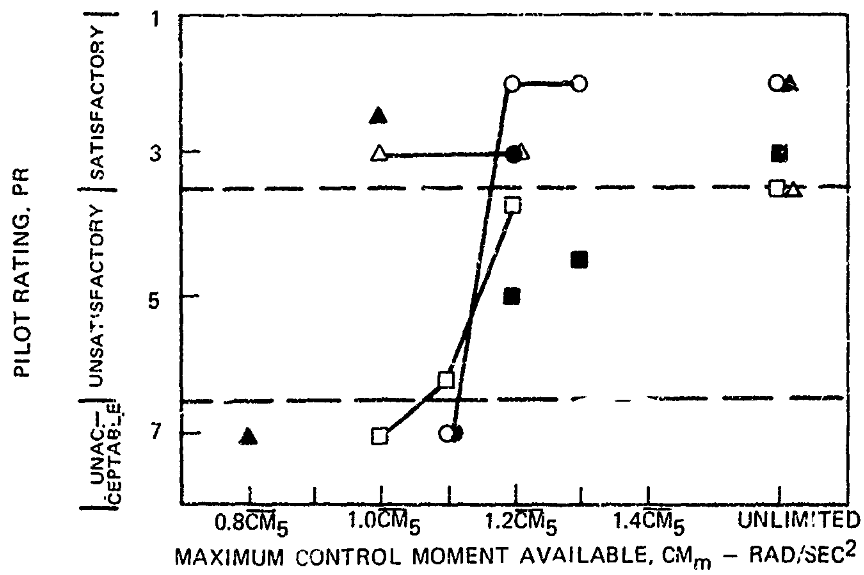
Figure 20. Lateral Control Sensitivity Results Showing the Effects of First-Order Control Lag

BASIC CONF.	BC1		BC4		BC5		BC6	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆

FIVE PERCENT EXCEEDANCE LEVELS, $\overline{CM}_5$ FOR PITCH, ROLL, AND YAW, RESPECTIVELY, WERE:

BASIC CONF.	BC1	BC4	BC5	BC6
PITCH, $\overline{M}_{C_5}$	0.330	0.820	0.380	0.890
ROLL, $\overline{L}_{C_5}$	0.380	0.605	0.360	0.750
YAW, $\overline{N}_{C_5}$	0.110	0.175	0.150	0.170

(a) LEVEL 1 CONFIGURATIONS FOR UNLIMITED CONTROL MOMENTS



(b) LEVEL 2 CONFIGURATION FOR UNLIMITED CONTROL MOMENTS

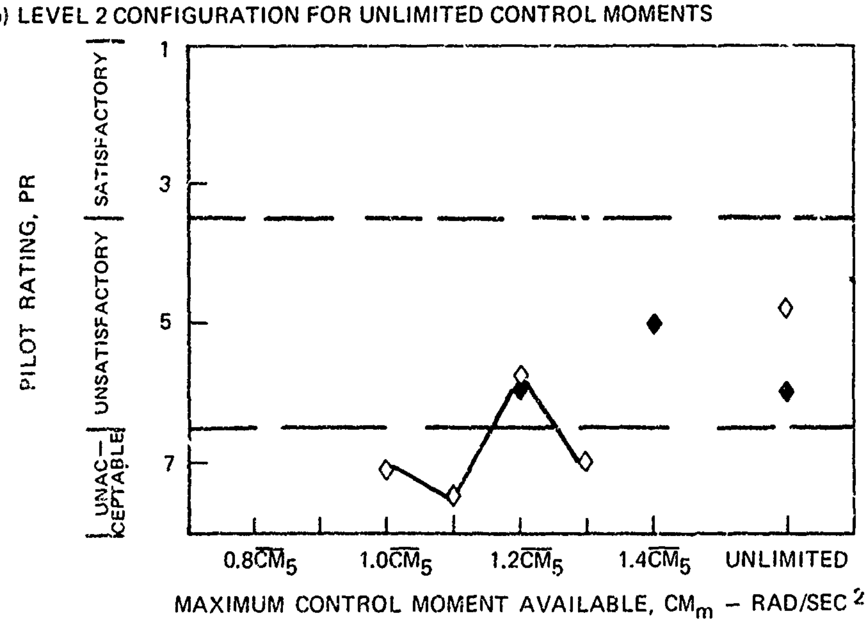


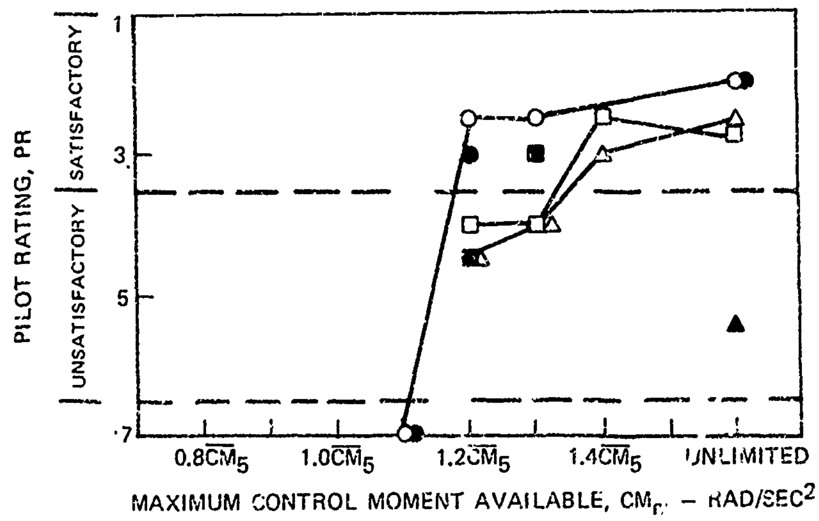
Figure 21. Pilot Rating Results for Control Moment Limits

LAG TIME CONSTANT	$\tau_e = \tau_a = 0$		$\tau_e = \tau_a = 0.3$		$\tau_e = \tau_a = 0.6$	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

0.1 SEC DELAY IN CONTROL RESPONSE FOR ALL TEST CASES

$\overline{CM}_5$: AVERAGED 5 PERCENT EXCEEDANCE MOMENT LEVELS FOR PITCH, ROLL, YAW

(a) BC1 $\overline{CM}_5$ = 0.330, 0.380, 0.110 RAD/SEC^2 FOR PITCH, ROLL, YAW, RESPECTIVELY



(b) BC5 $\overline{CM}_5$ = 0.380, 0.360, 0.150 RAD/SEC^2 FOR PITCH, ROLL, YAW, RESPECTIVELY

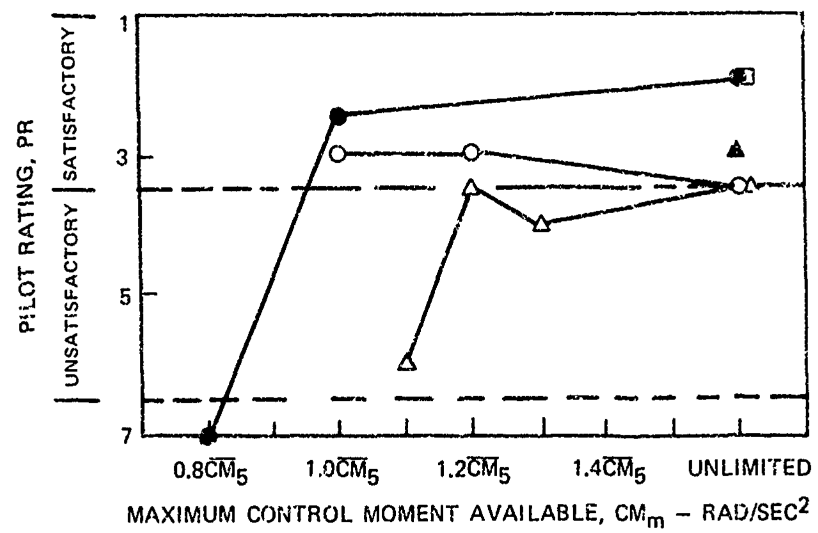


Figure 22. Pilot Ratings Showing the Effects of Control Moment Limits with First-Order Control System Lags

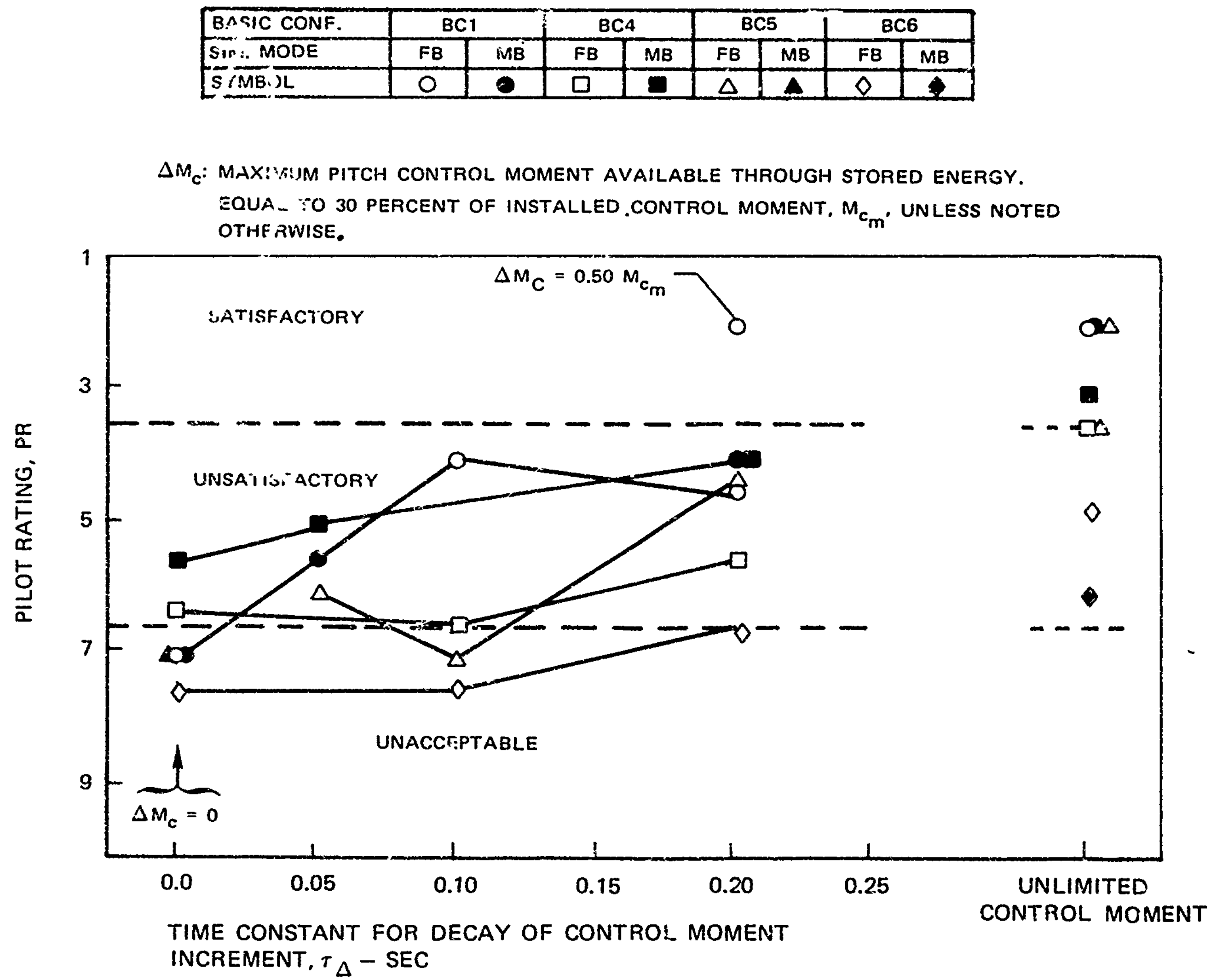


Figure 23. Change in Pilot Rating with Level of Incremental Pitch Control-Moment Available Through Stored Energy

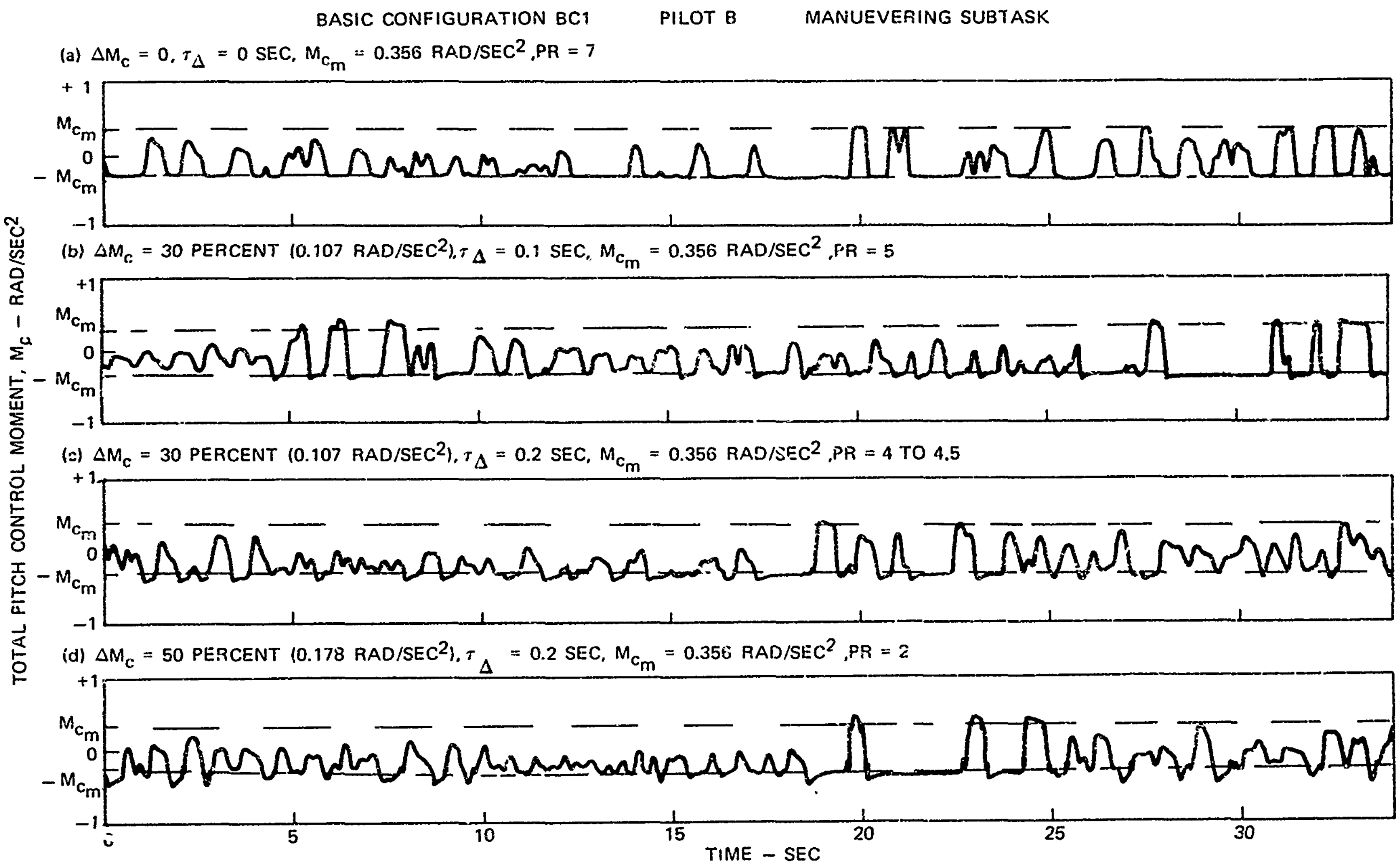


Figure 24. Time Histories of Pitch Control-Moment Usage for the Maneuvering Task with Incremental Moment Available Through Stored Energy

$M_{\delta_a}/L_{\delta_a} = -L_{\delta_e}/M_{\delta_e}$	0		0.25		0.50	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

CONFIGURATION BC1 EXCEPT WHERE OTHERWISE INDICATED

* CONTROL AND RATE COUPLING EFFECTS ADDITIVE, I.E., CONTROL INPUTS CAUSE ATTITUDE RATES WHICH INDUCE COUPLING MOTION IN SAME DIRECTION AS CONTROL COUPLING, UNLESS OTHERWISE NOTED

DASHED LINES INDICATE MIL–F–83300 MINIMUM SENSITIVITY BOUNDARY. SEE NOTE ON FIG. 12.

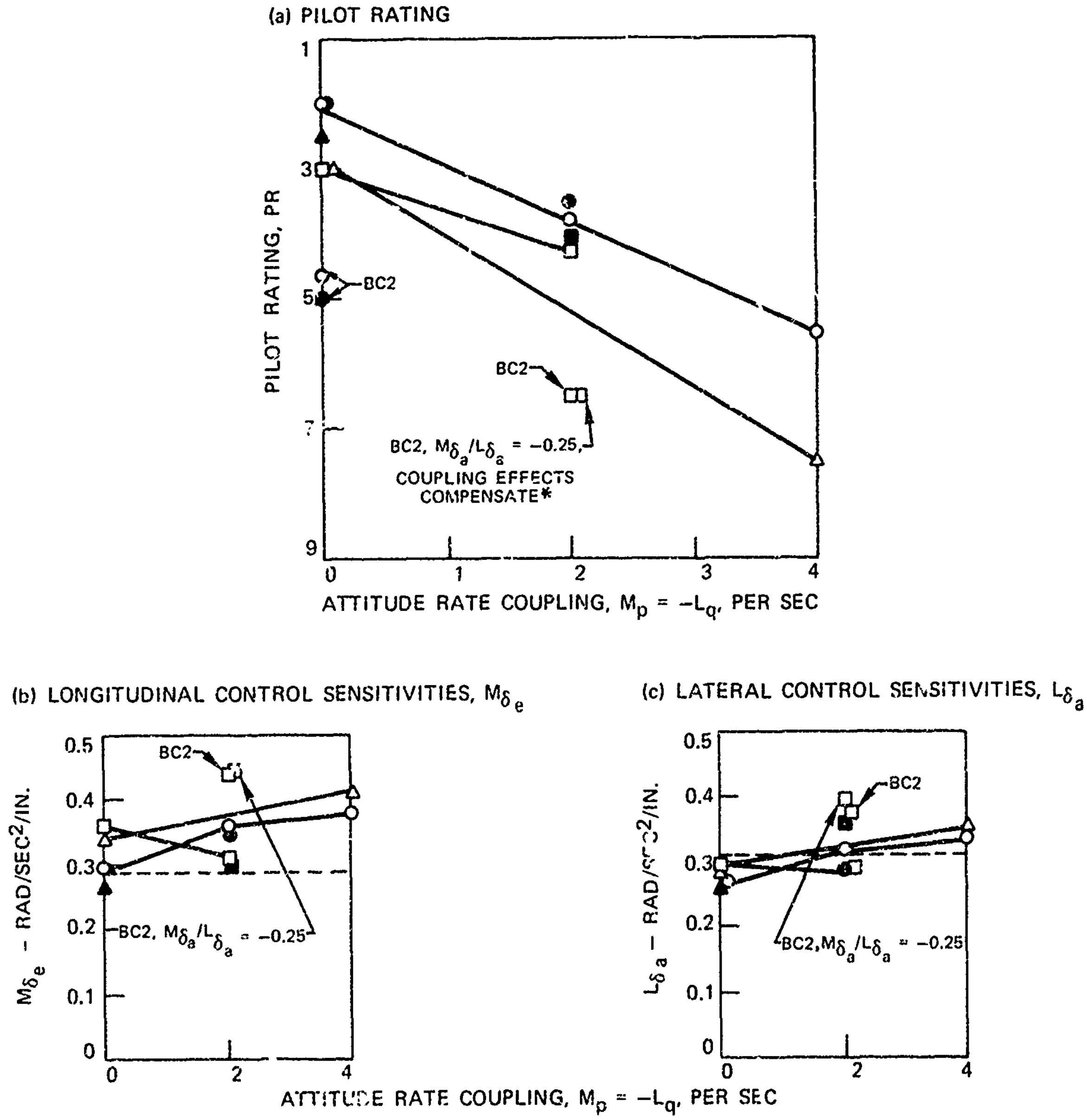


Figure 25. Effects of Inter-Axis Motion Coupling on Pilot Rating and Control Sensitivities

LEVEL*	1				2	
BASIC CONF.	BC1		BC4		BC2	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

THRUST VECTOR ANGLE, γ, DISPLAYED ON CONTACT ANALOG AND INSTRUMENT PANEL UNLESS NOTED OTHERWISE

* SEE NOTE ON LEVELS SHOWN ON FIG. 20.

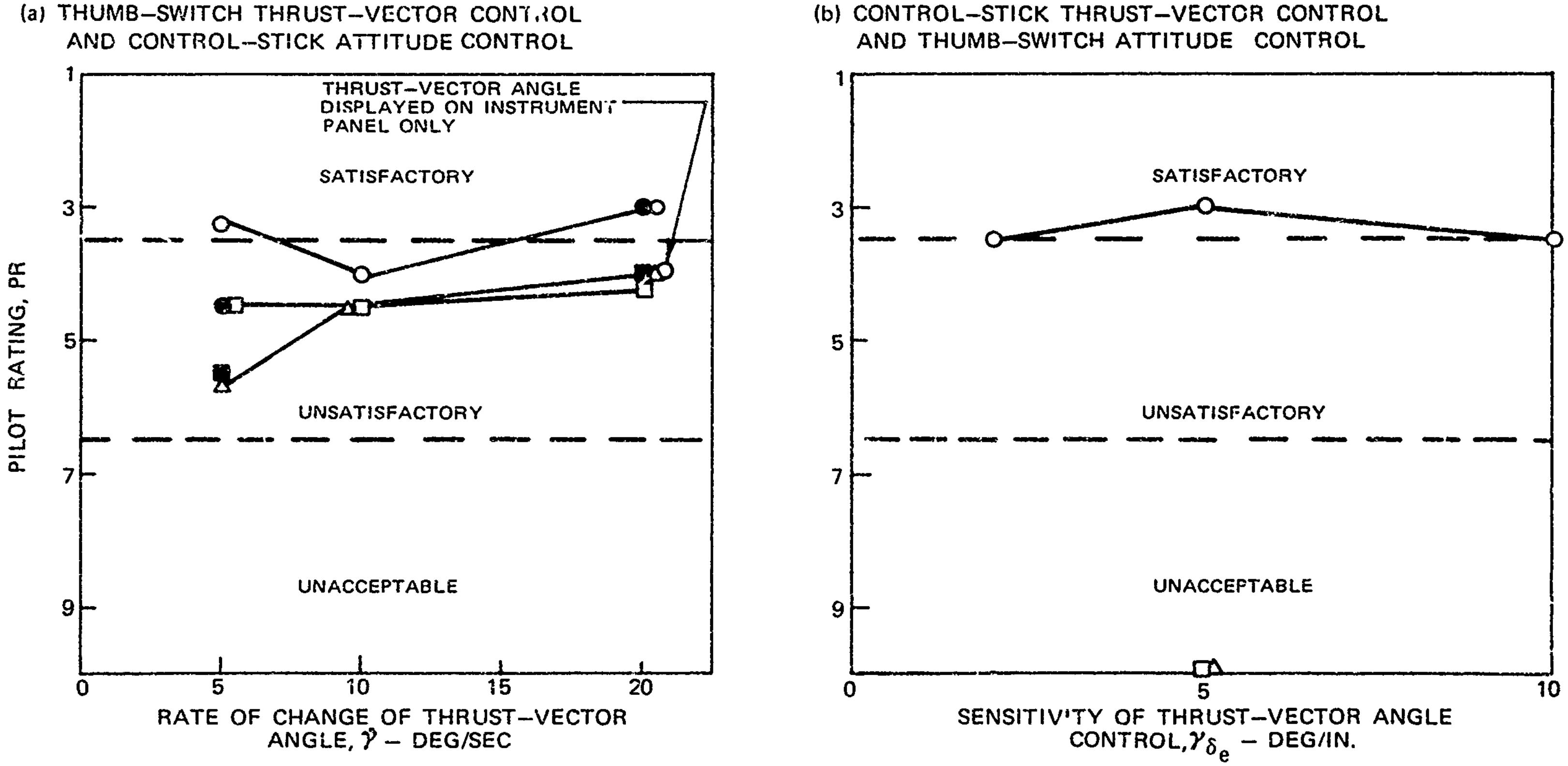


Figure 26. Pilot Rating Results from the Study of Independent Thrust-Vector Control

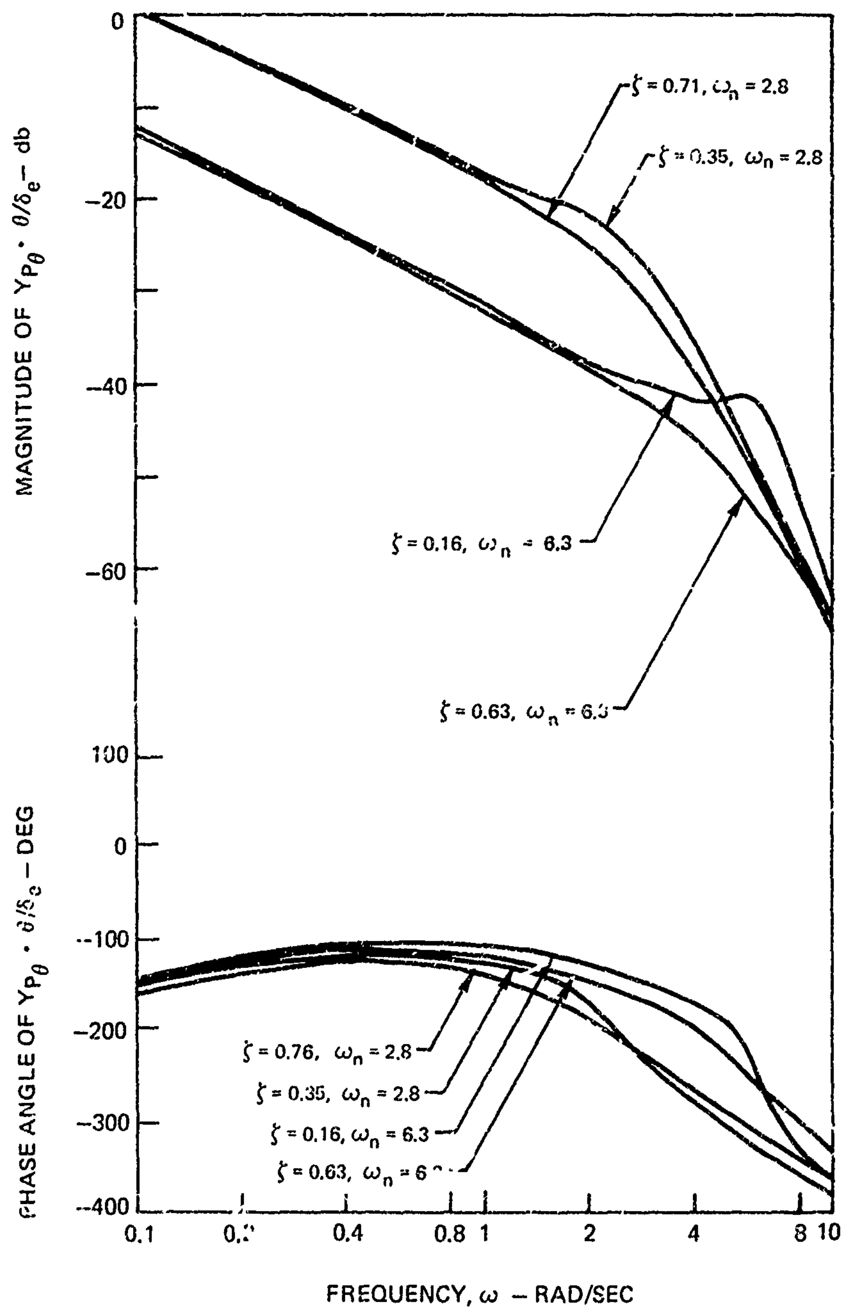
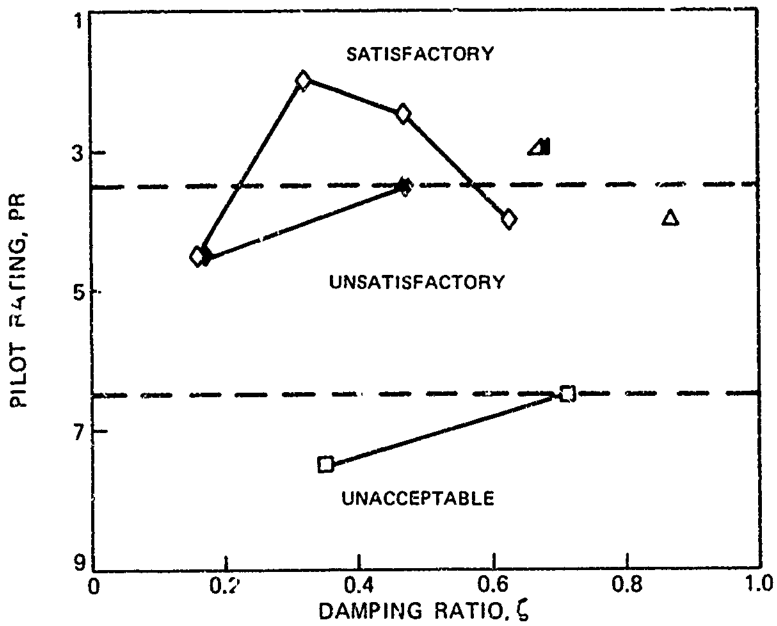


Figure 27. Magnitude and Phase Characteristics for Pilot-Pitch (Roll) Attitude Open-Loop Dynamics with Rate-Command/Attitude-Hold Control

(a) SPEED–STABILITY AND DRAG PARAMETERS OF CONFIGURATION BCI

NATURAL FREQUENCY, ω_n	2.30		3.44		6.30		7.40	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	□	■	△	▲	◇	◆	⊿	◢



(b) SPEED–STABILITY AND DRAG PARAMETERS OF CONFIGURATION BC4

NATURAL FREQUENCY, ω_n	4.0		5.0		7.4	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

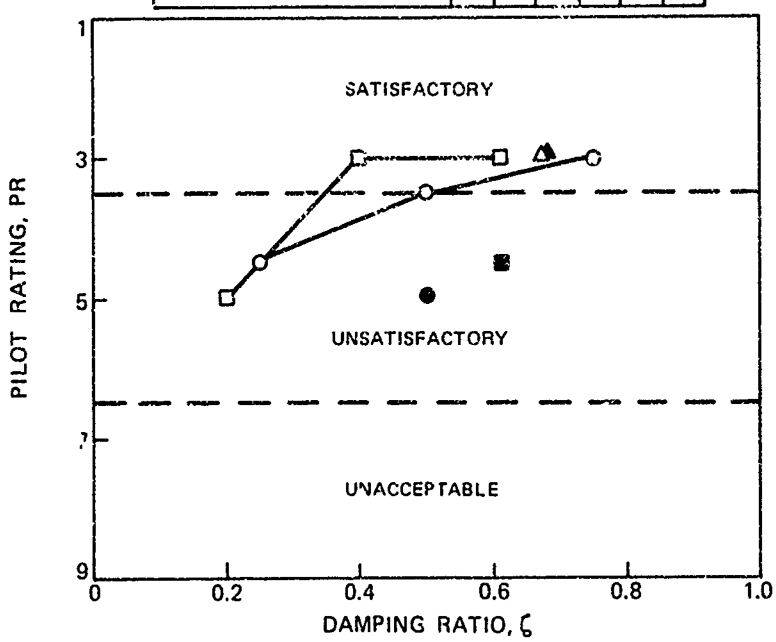
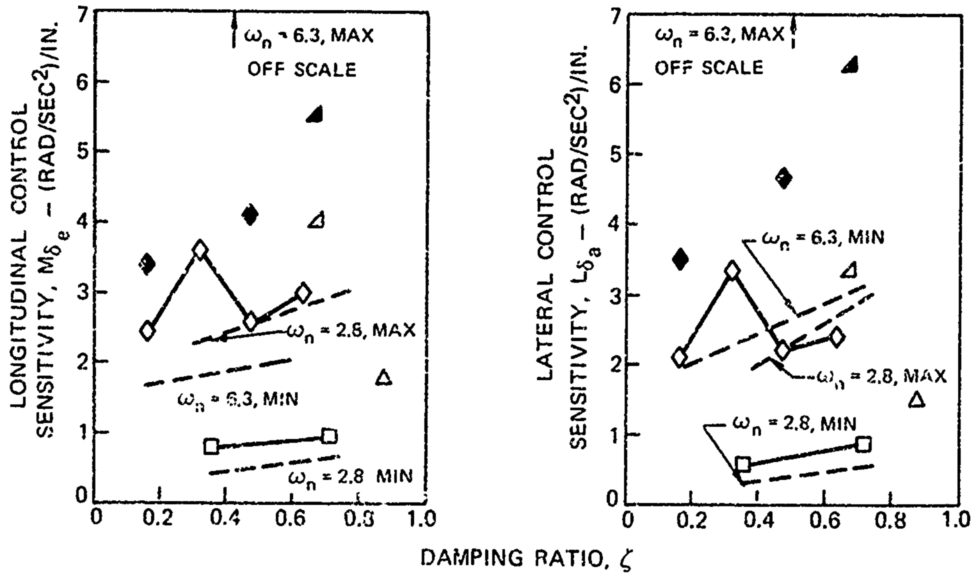


Figure 28. Pilot Rating Results for a Rate-Command/Attitude-Hold Control System

(a) SPEED–STABILITY AND DRAG PARAMETERS OF CONFIGURATION BCI

NATURAL FREQUENCY, ω_n	2.80		3.44		6.30		7.40	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	□	■	△	▲	◇	◆	⊿	◢

DASHED LINES SHOW MIL–F–83300 BOUNDARIES. SEE NOTE ON FIG. 12.



(b) SPEED–STABILITY AND DRAG PARAMETERS OF CONFIGURATION BC4

NATURAL FREQUENCY, ω_n	4.0		5.0		7.4	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

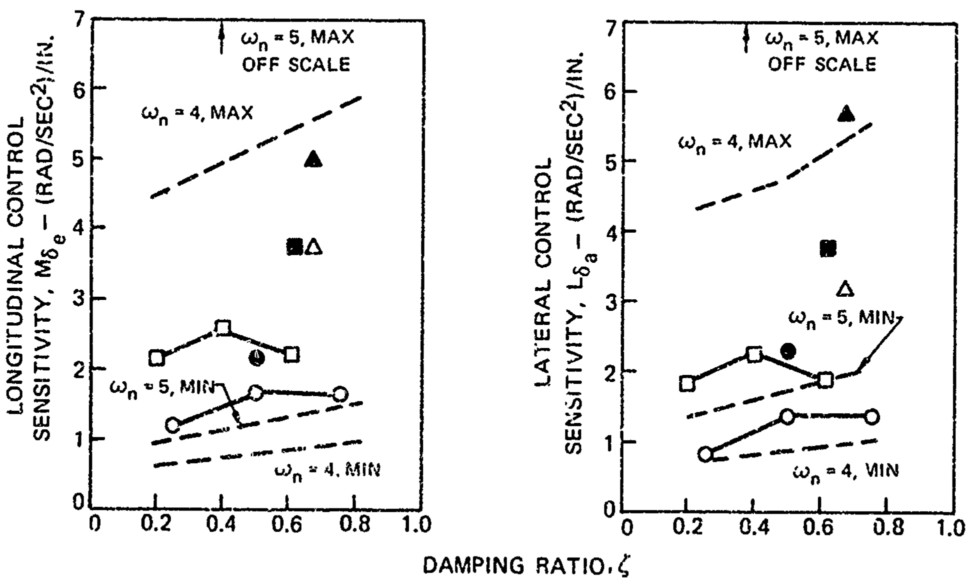


Figure 29. Control Sensitivities from the Study of Rate-Command/Attitude-Hold Control

RMS TURBULENCE INTENSITY, FT/SEC	3.4	6.8	8.2
SYMBOL	○	□	△

CONFIGURATION BC1 $M_{u\theta} = -L_{v\theta} = 0.33$ LEVEL 1*

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

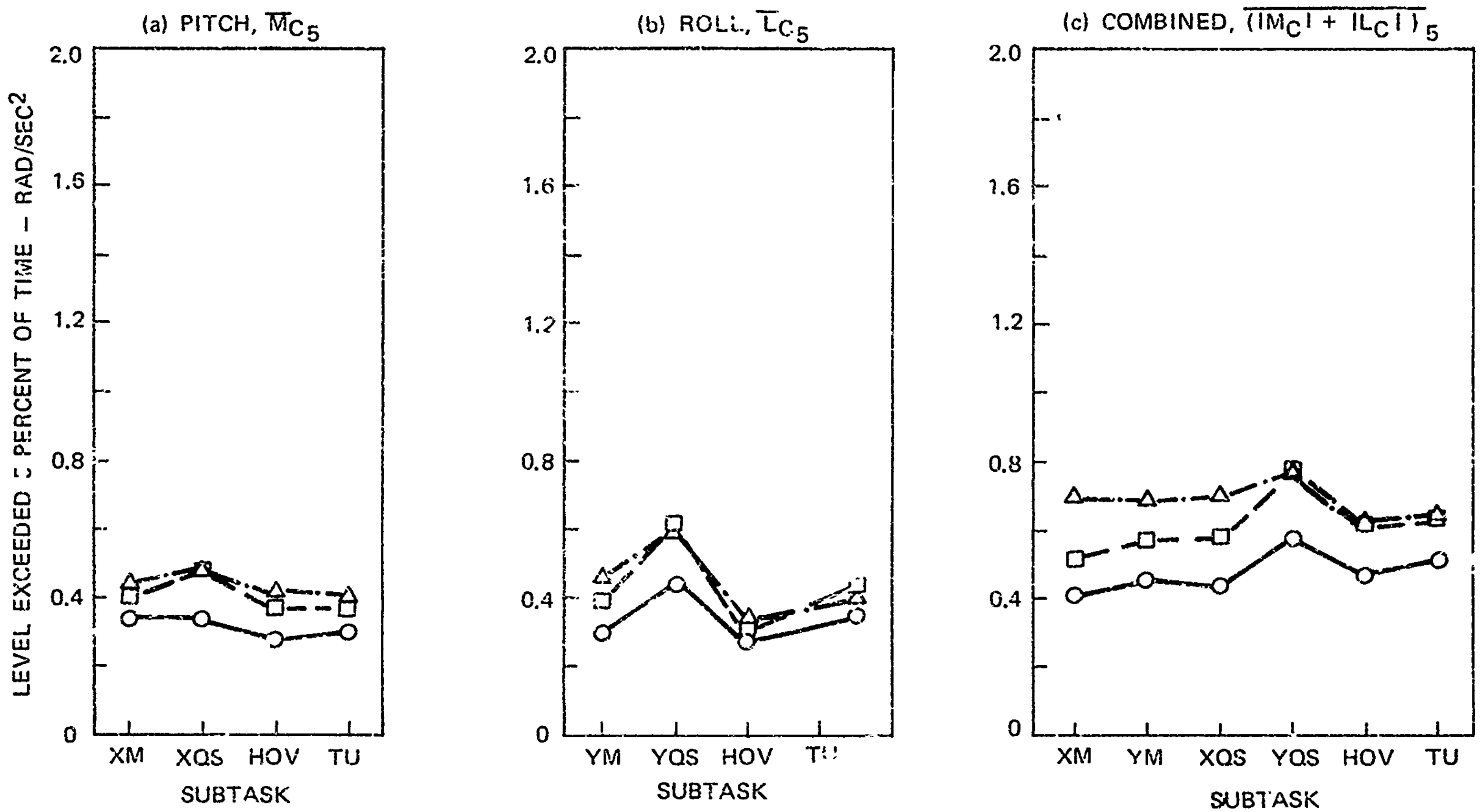


FIGURE 30. Effect of Turbulence on Five-Percent Exceedance Moment Level for a V/STOL Configuration with Small Response to Turbulence

RMS TURBULENCE INTENSITY, FT/SEC	3.4	5.8	8.2
SYMBOL	○	□	△

CONFIGURATION BC6 $M_{u_g} = -L_{v_g} = 1.0$ LEVEL 2*

* LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

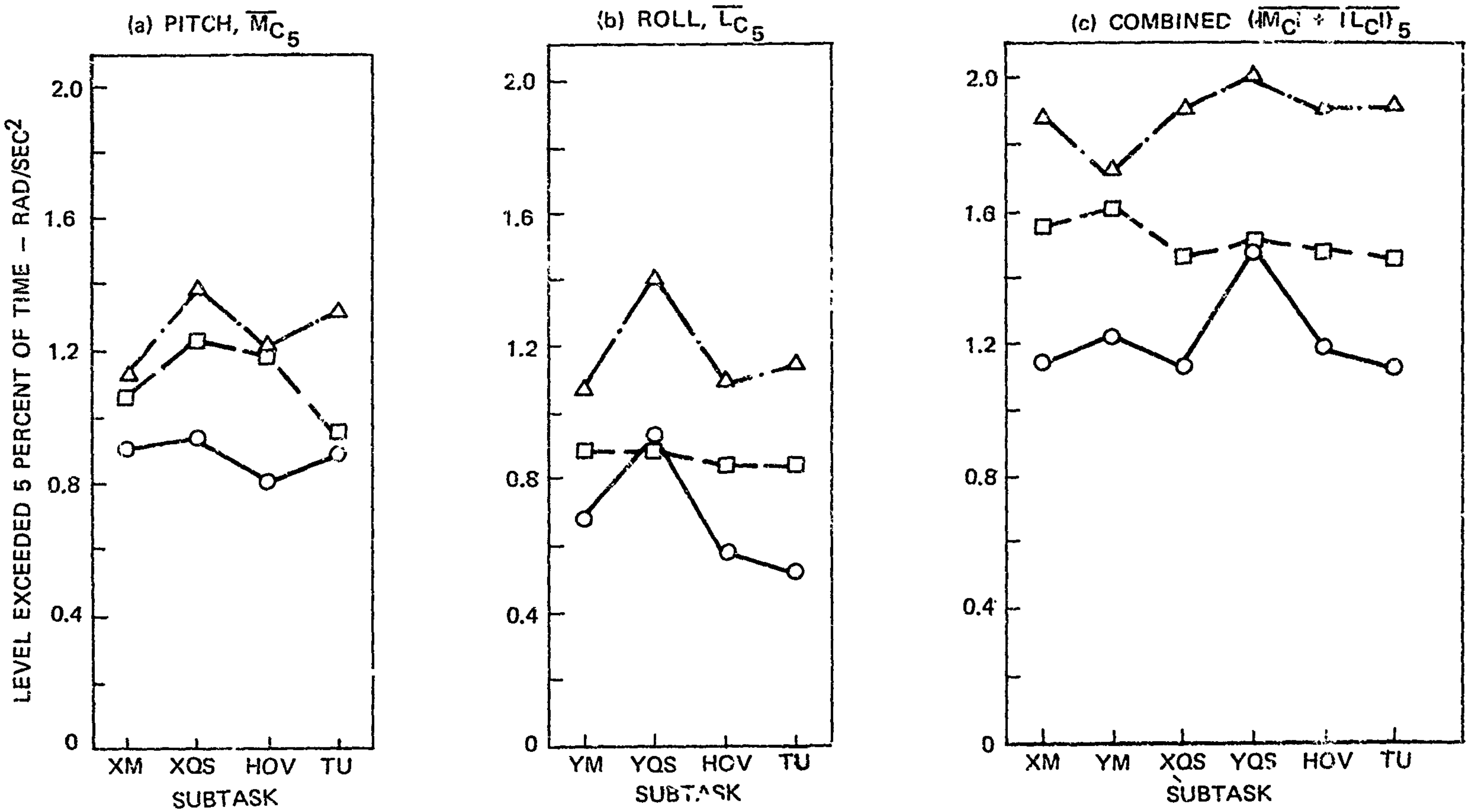


FIGURE 31. Effect of Turbulence on Five-Percent Exceedance Moment Level for a V/STOL Configuration with Large Response to Turbulence

BASIC CONF.	BC5	BC4
$M_{ug} = -L_{vg}$	0.33	1.0
SYMBOL	○	□

BC5, BC4 LEVEL 1 CONFIGURATIONS $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

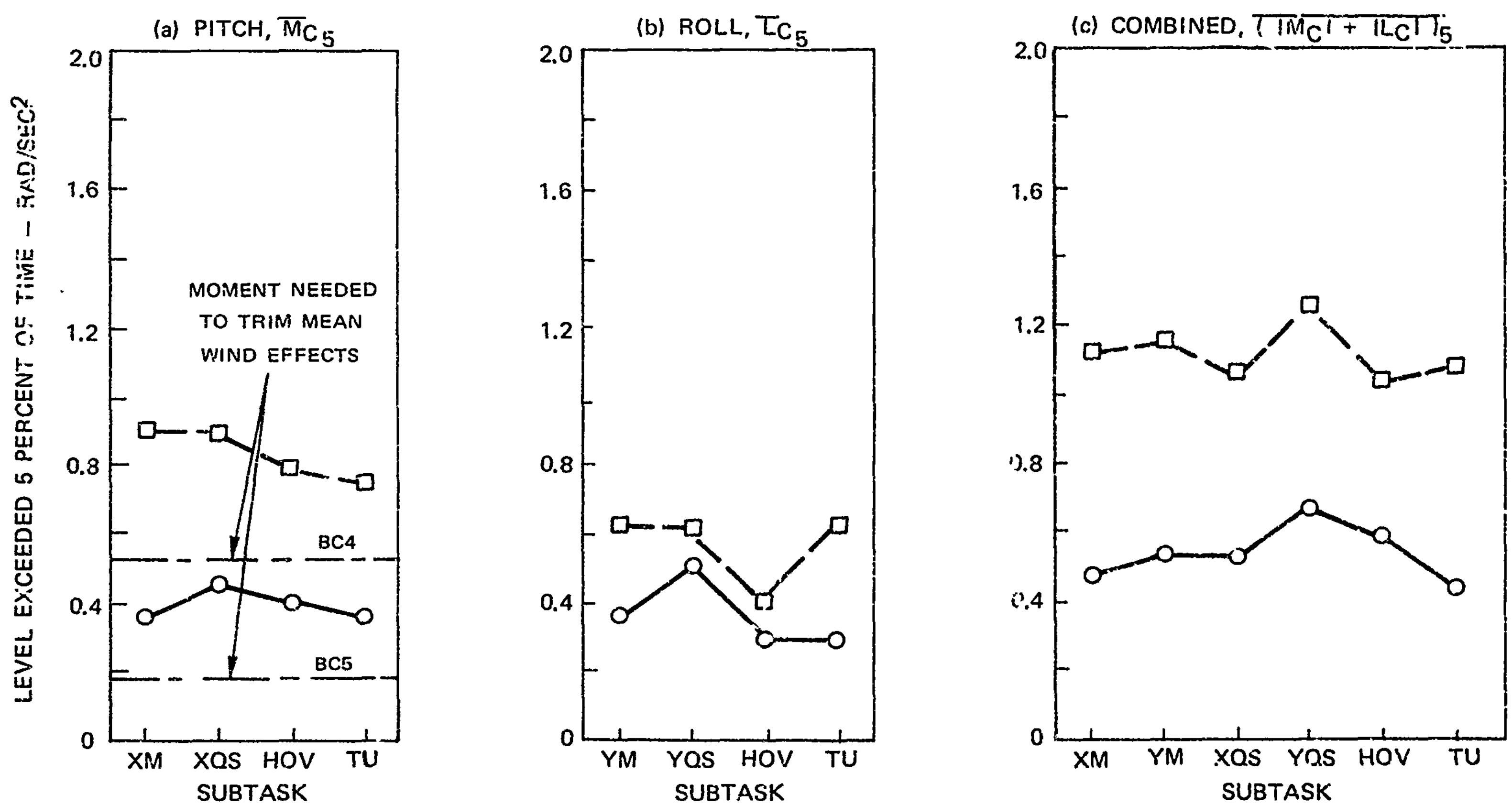


FIGURE 32. Five-Percent Exceedance Moment Levels Showing the Effect of Aircraft Speed-Stability Parameters

BASIC CONF.	BC1	BC5
$X_u = Y_v$	−0.05	−0.20
SYMBOL	○	□

BC1, BC5 LEVEL 1 CONFIGURATIONS $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

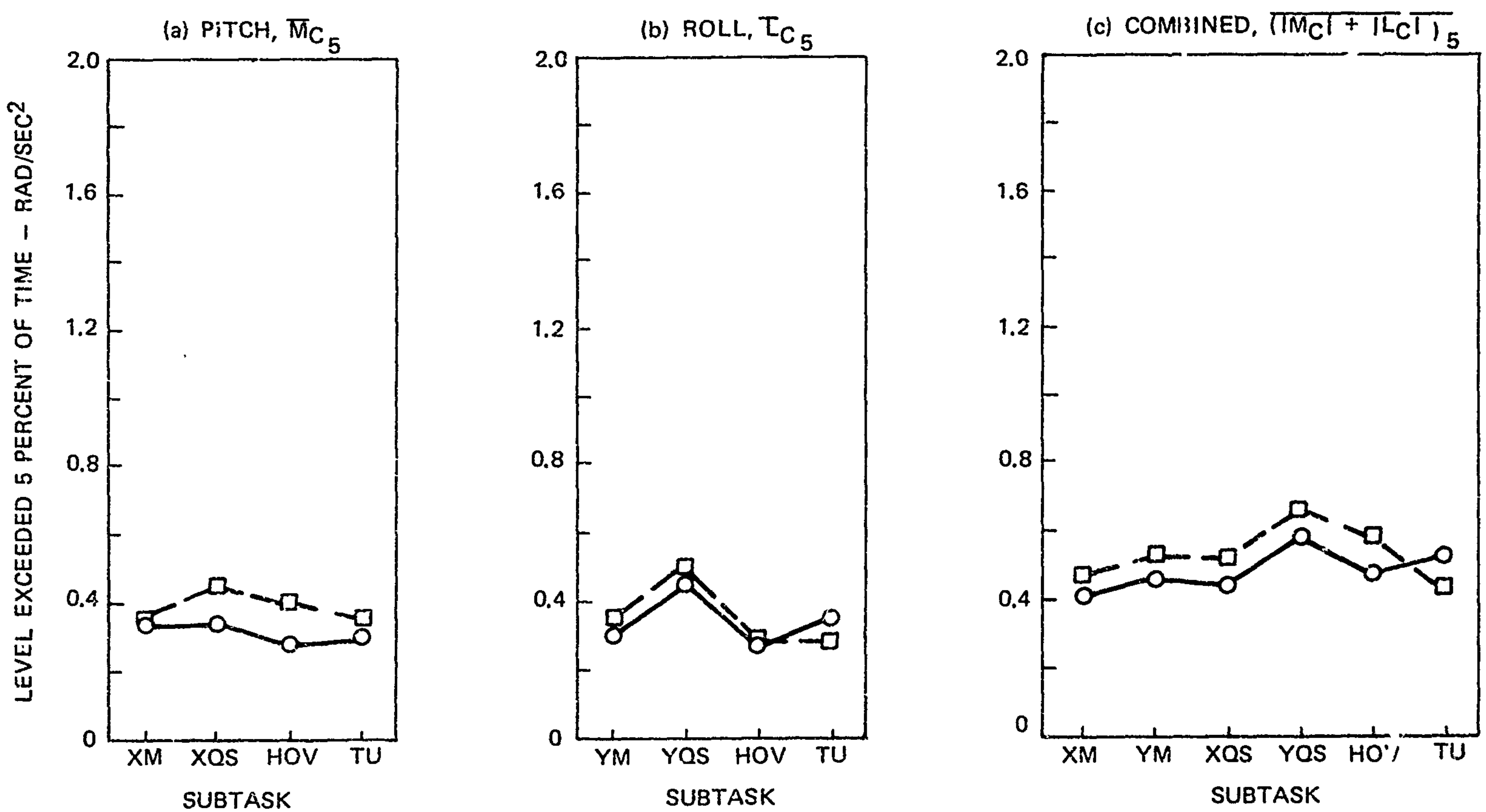


FIGURE 33. Five-Percent Exceedance Moment Levels for V/STOL Configurations Having Different Drag Parameters

LEVEL	1	2	3
BASIC CONF.	BC4	BC2	BC3
SYMBOL	○	□	△

$M_{u_g} = -L_{v_g} = 1.0$ FOR BC4, BC2, BC3 $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

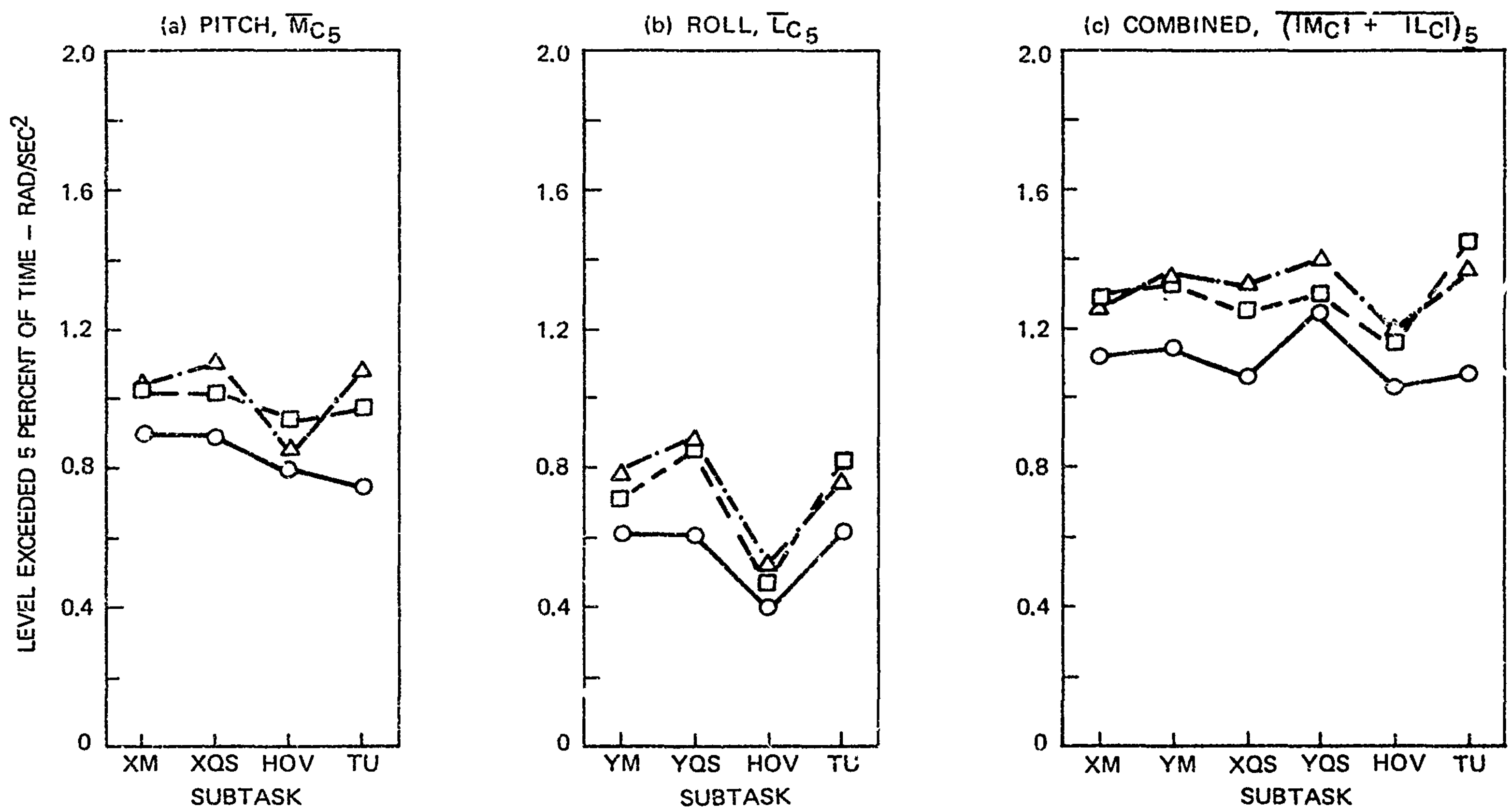


FIGURE 34. Five-Percent Moment Levels for Three V/STOL Configurations Exhibiting the Three MIL-F-83300 Levels of Flying Qualities

CONTROL LAG	0	0.3	0.6
SYMBOL	○	□	△

CONFIGURATION 8C5 LEVEL 1* $M_{u_g} = -L_{v_g} = 0.33$ $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

*LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

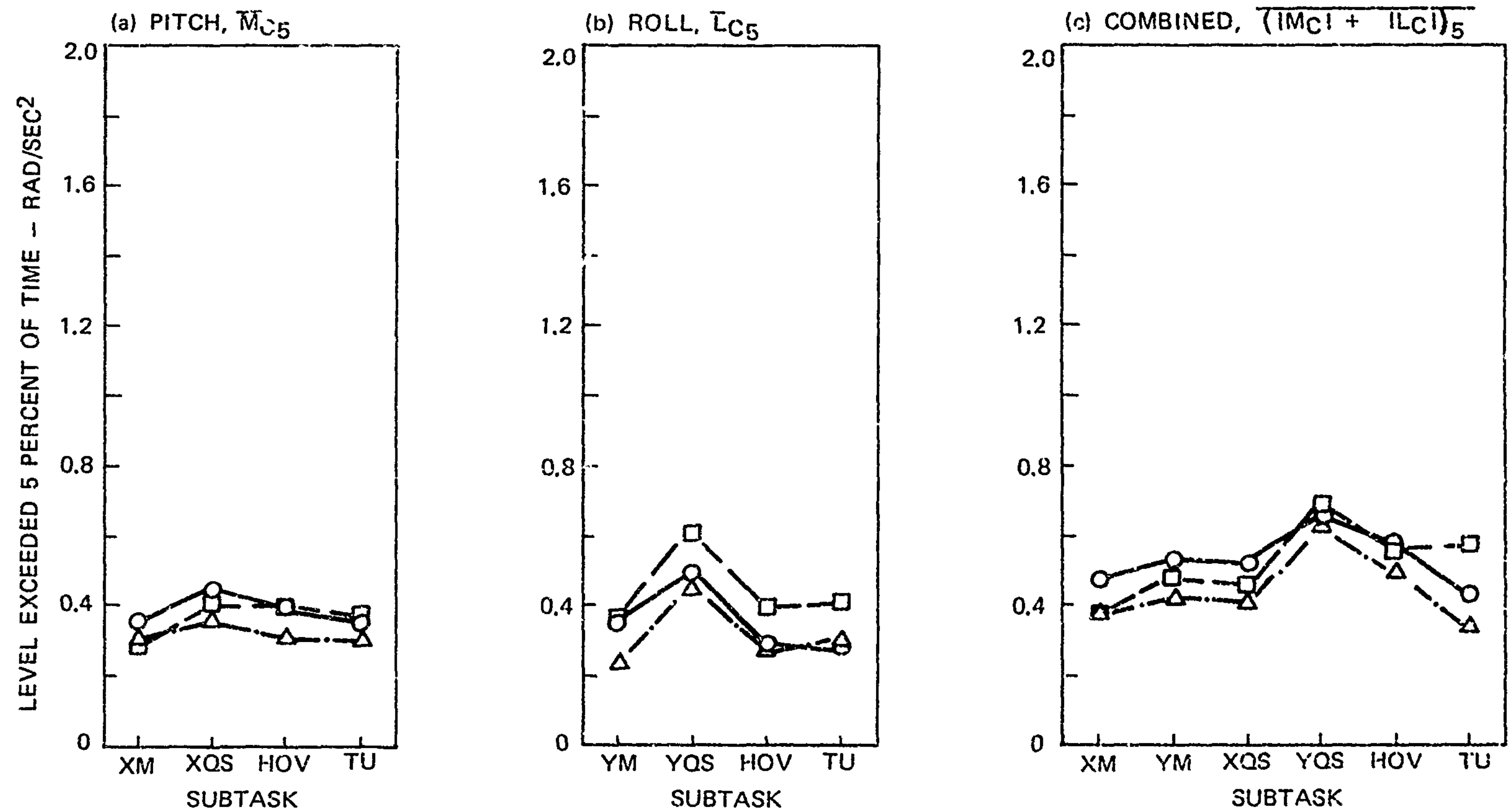


FIGURE 35. Effects of Control Lags on Five-Percent Moment Levels for Configuration with Low Response to Turbulence

CONTROL LAG	0	0.3	0.6
SYMBOL	○	□	△

CONFIGURATION BC4 LEVEL 1 * $M_{u_g} = -L_{v_g} = 1.0$ $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

*LEVEL APPLIES TO BASIC CONFIGURATION ONLY. DUE TO PARAMETER VARIATIONS, THE LEVEL SHOWN GENERALLY DOES NOT DESCRIBE FLYING QUALITIES OF TEST CASES.

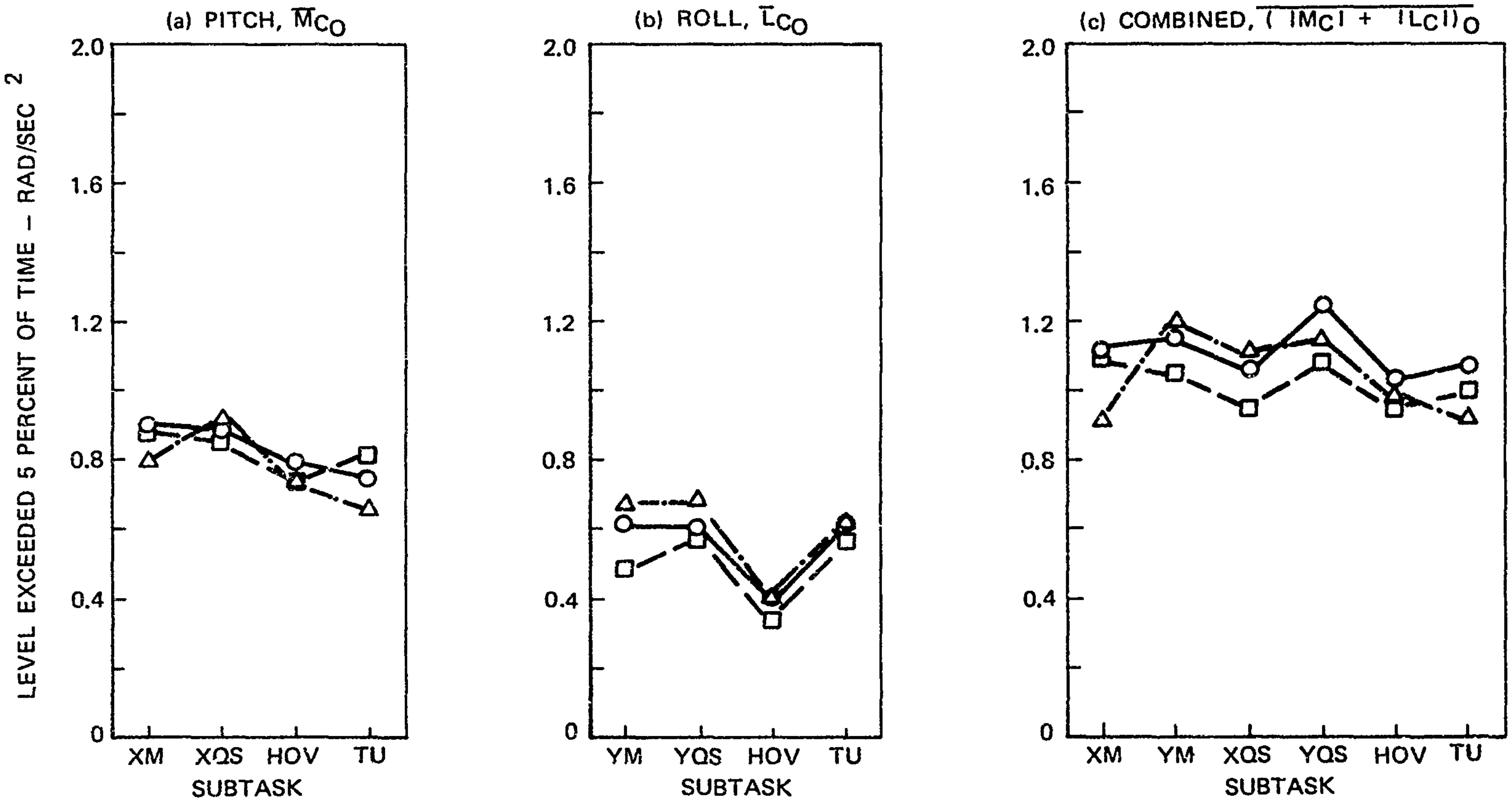


FIGURE 36. Effects of Control Lags on Five-Percent Moment Levels for Configuration with Moderate Response to Turbulence

$M_{\delta_a}/L_{\delta_a} = -L_{\delta_e}/M_{\delta_e}$	0		0.25		0.50	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

CONFIGURATION BC1 CONTROL AND RATE COUPLING EFFECTS ADDITIVE (SEE FIG. 25 FOR EXPLANATION)

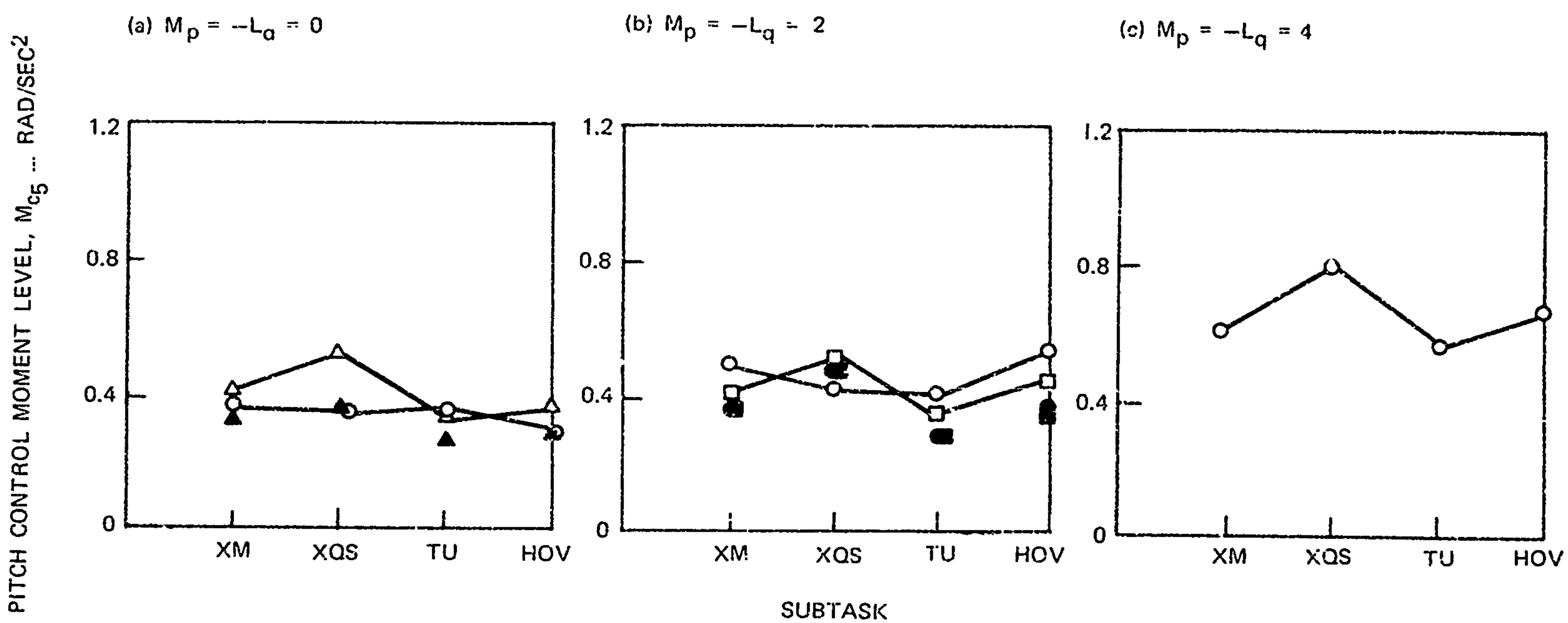


Figure 37. Effect of Rate and Control Coupling on Pitch 5-Percent Exceedance Control-Moment Level

LEVEL	1			2		3
BASIC CONF.	BC 1	BC5	BC 4	BC 2	BC6	BC3
SYMBOL	○	□	△	◇	◺	◗

$\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

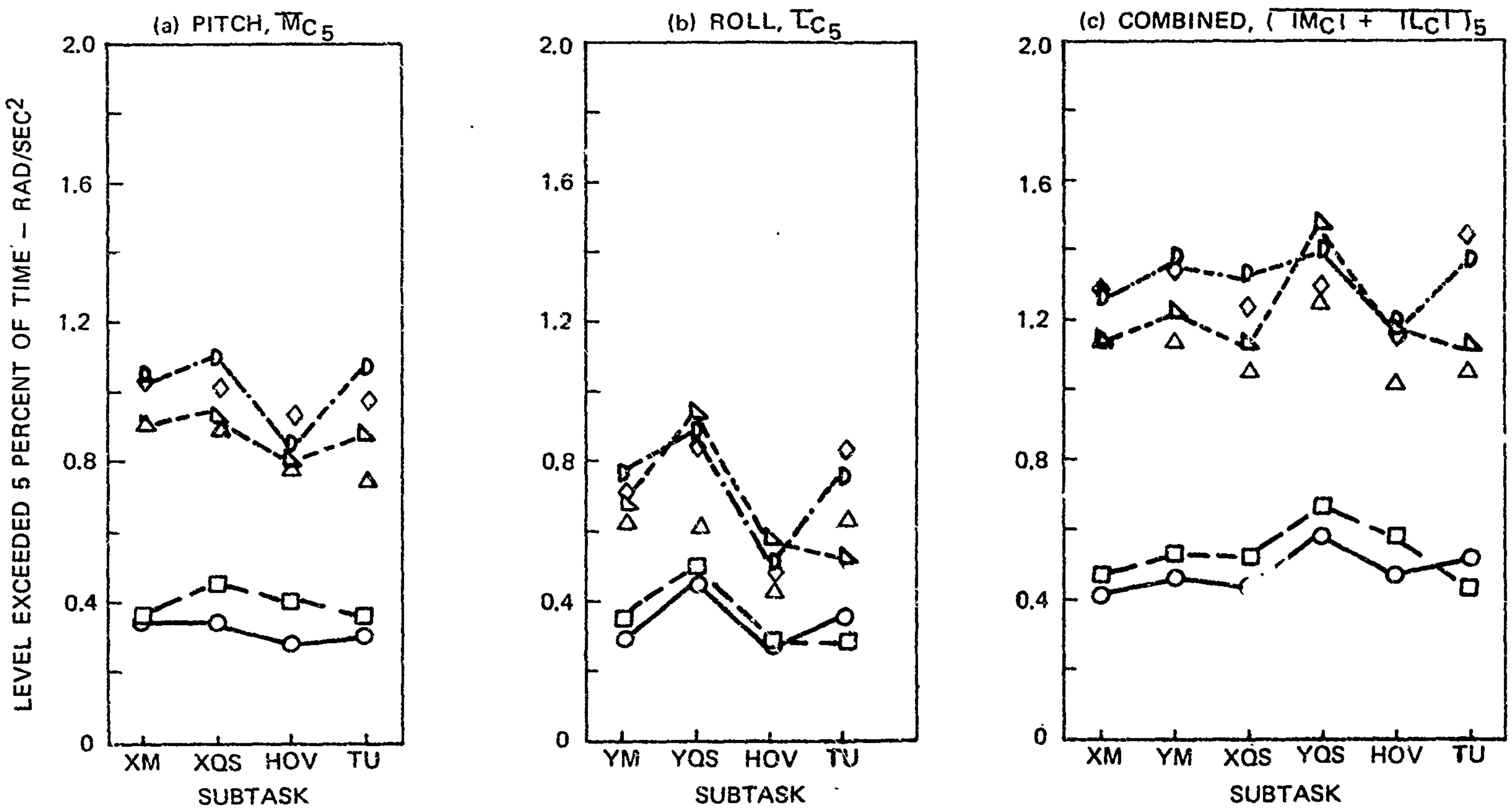


FIGURE 38. Effect of Subtask on Five-Percent Control-Moment-Exceedance Level

CONTROL MOMENT	$\overline{(\lvert M_C \rvert + \lvert L_C \rvert)}_5$	$\overline{M_C}_5 + \overline{L_C}_5$	$\sqrt{\overline{M_C}_5^2 + \overline{L_C}_5^2}$
SYMBOL	○	□	△

HOVER SUBTASK $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

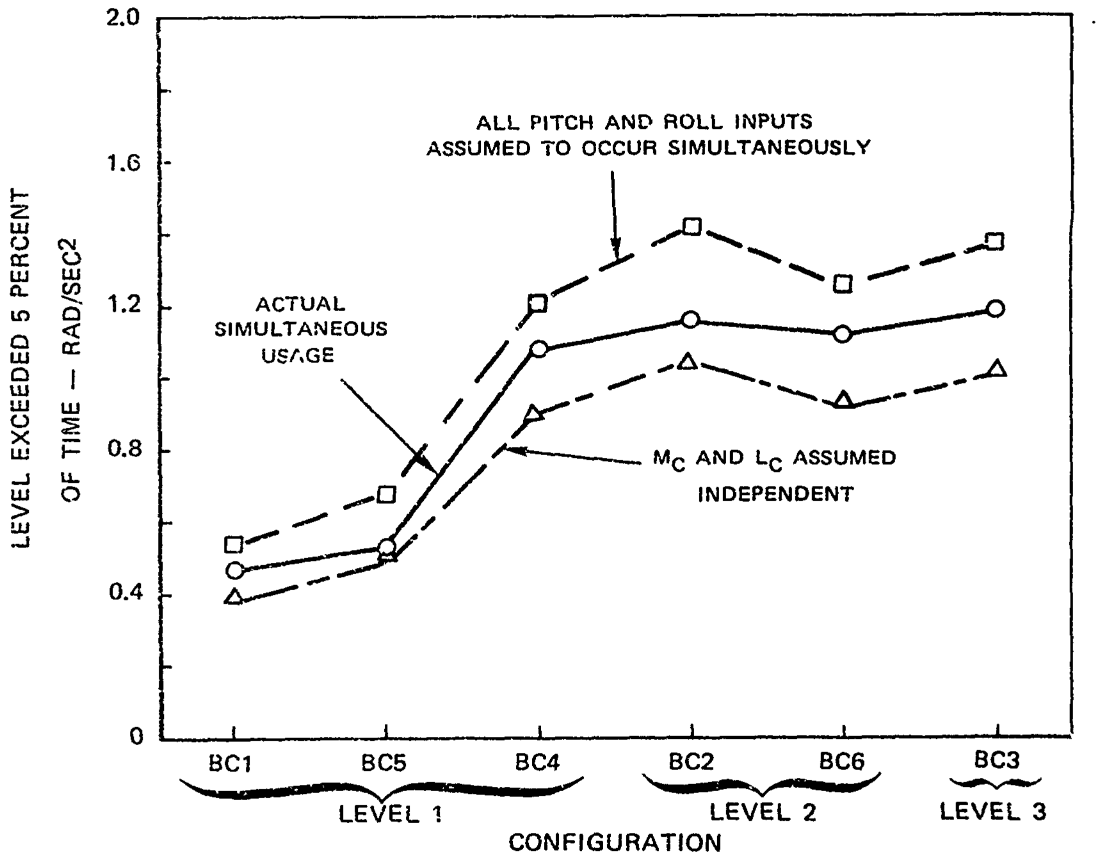
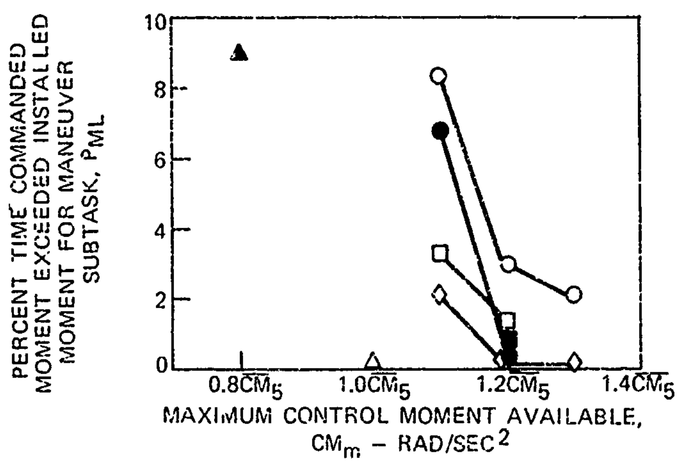


Figure 39. Comparison of Actual Five-Percent Simultaneous Usage Moment Levels for Hover with Hypothetical Maximum and Minimum Values for these Levels

BASIC CONF.	BC1		BC4		BC5		BC6	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲	◇	◆

$\overline{CM}_5$: AVERAGED 5-PERCENT EXCEEDANCE MOMENT LEVELS FOR PITCH AND ROLL WITH UNLIMITED CONTROL MOMENT AVAILABLE

(a) PITCH CONTROL



(b) ROLL CONTROL

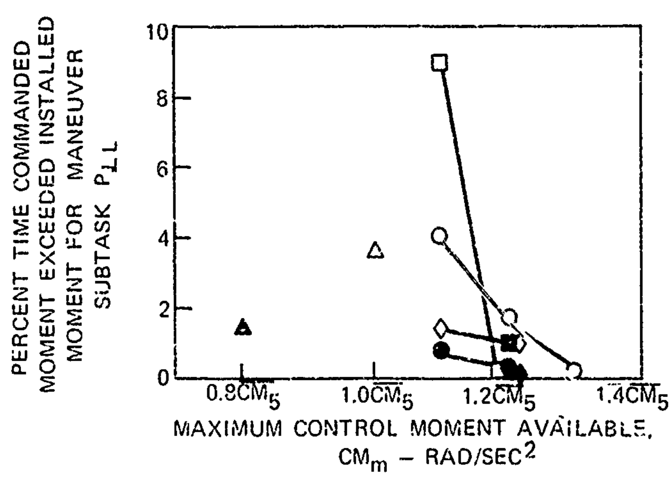


Figure 40. Percent Time Total Moment Command Exceeded Installed Pitch and Roll Control Moments for Flight with Limited Available Moments

TYPE OF POSITION CONTROL	CONVENTIONAL	INDEPENDENT THRUST-VECTOR CONTROL
SYMBOL	O	□

FIXED BASE

THUMB-SWITCH THRUST-VECTOR CONTROL, $\dot{\gamma}$ = 20 DEG/SEC, AND CONTROL-STICK ATTITUDE CONTROL FOR INDEPENDENT THRUST-VECTOR CONTROL

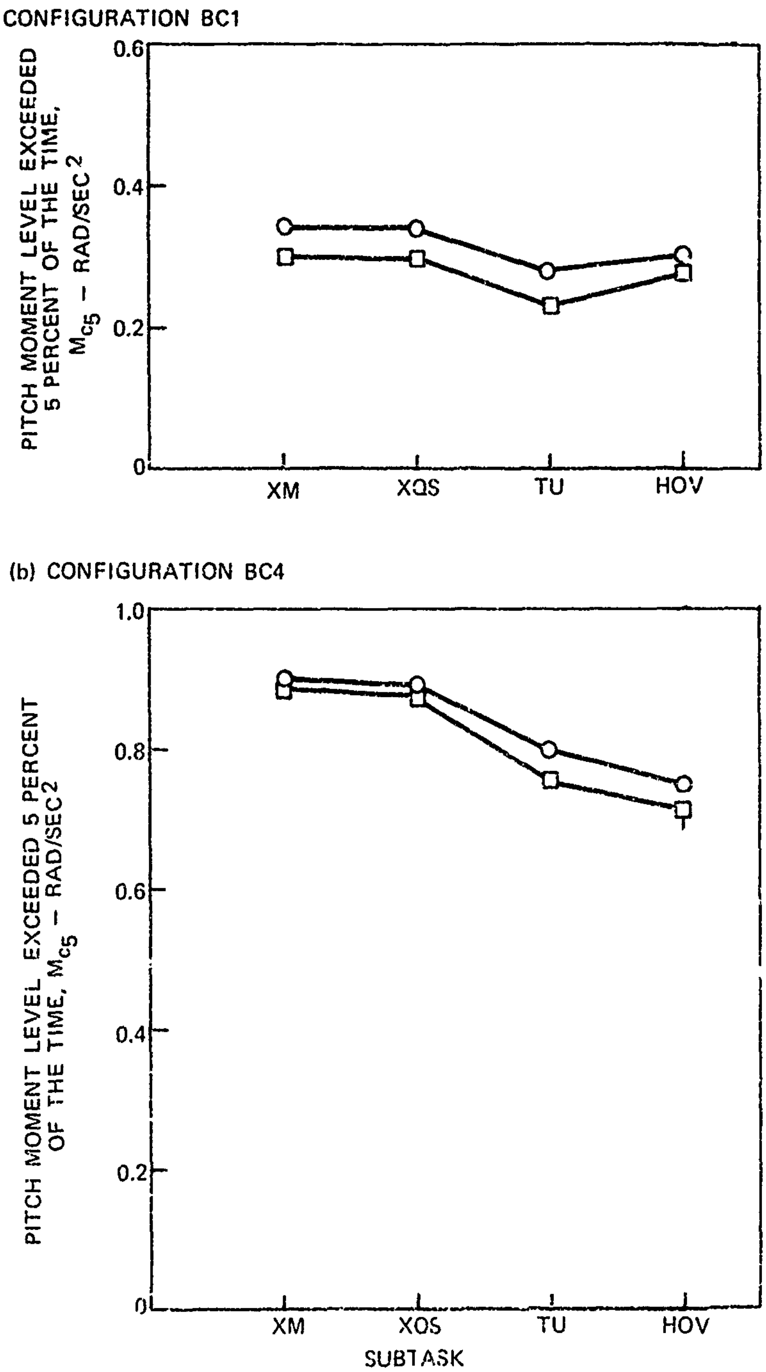
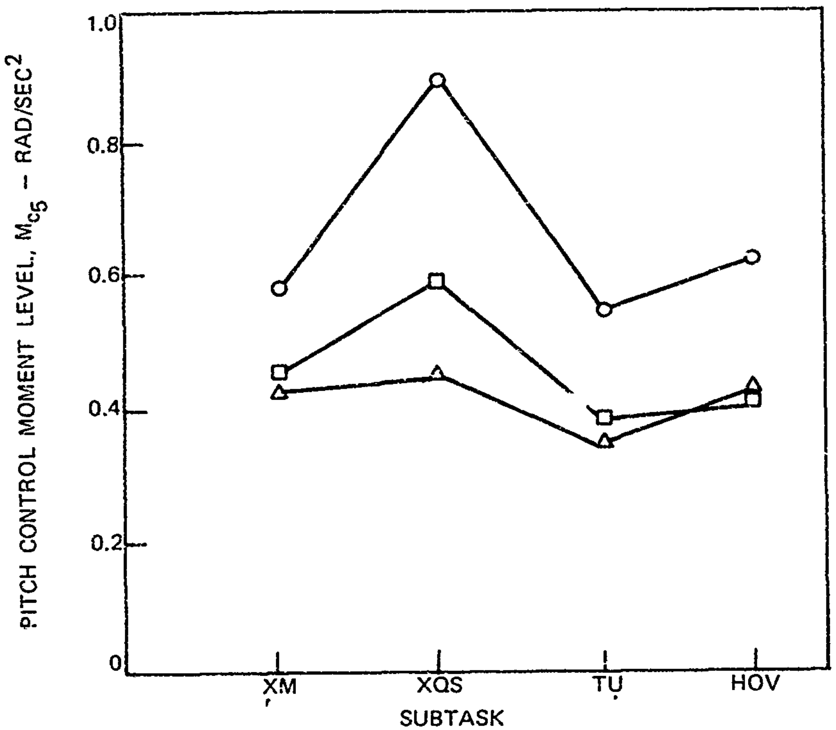


Figure 41. Comparison Between Pitch Control-Moment 5-Percent Exceedance Levels for Independent Thrust-Vector Control and Conventional Position Control

CONFIGURATION RC1

(a) ω_n = 2.8 AND 3.4 RAD/SEC

ω_n	2.8				3.4	
ζ	0.35		0.71		0.87	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲



(b) ω_n = 6.3 RAD/SEC

ζ	0.16		0.47	
SIMULATOR MODE	FB	MB	FB	MB
SYMBOL	○	●	□	■

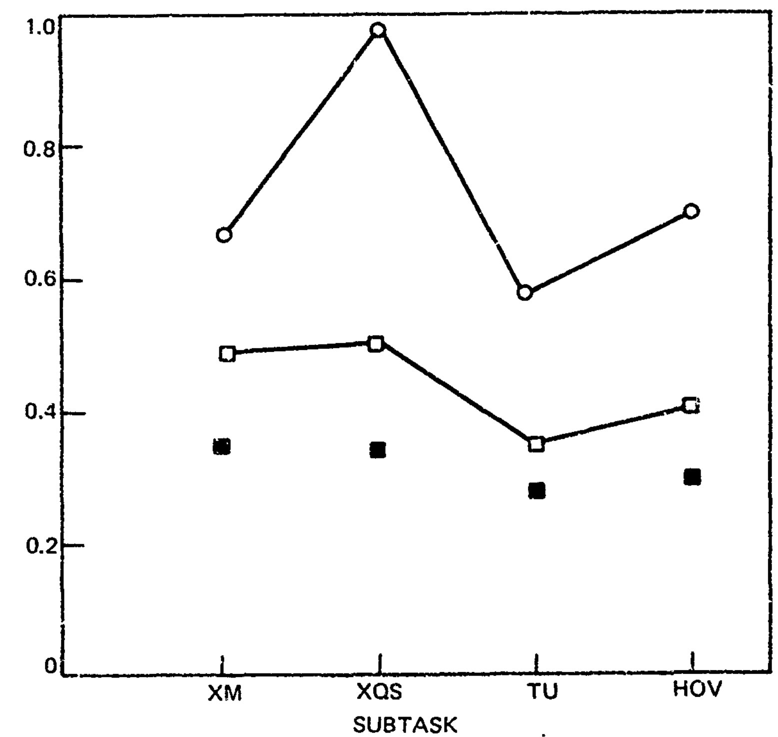


Figure 42. Five-Percent Pitch Control-Moment Exceedance Levels for Rate-Command/Attitude-Hold Control System

PILOT	CALSPAN B*	UARL	
SIMULATOR MODE	MB	FB	MB
SYMBOL	●	□	■

* NO SIMULATED WINDS FOR CALSPAN PILOT EVALUATION

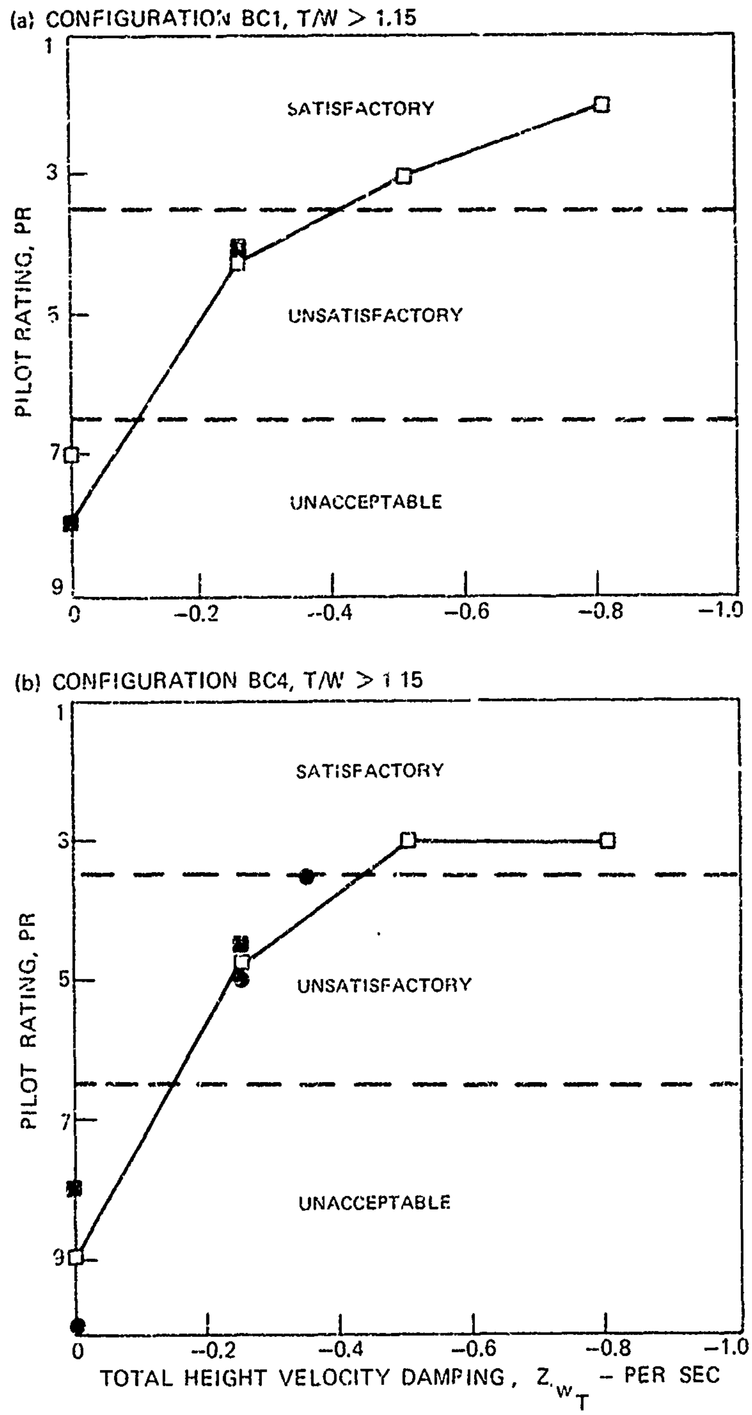


Figure 43. Change in Pilot Rating of Height Control with Height Velocity Damping

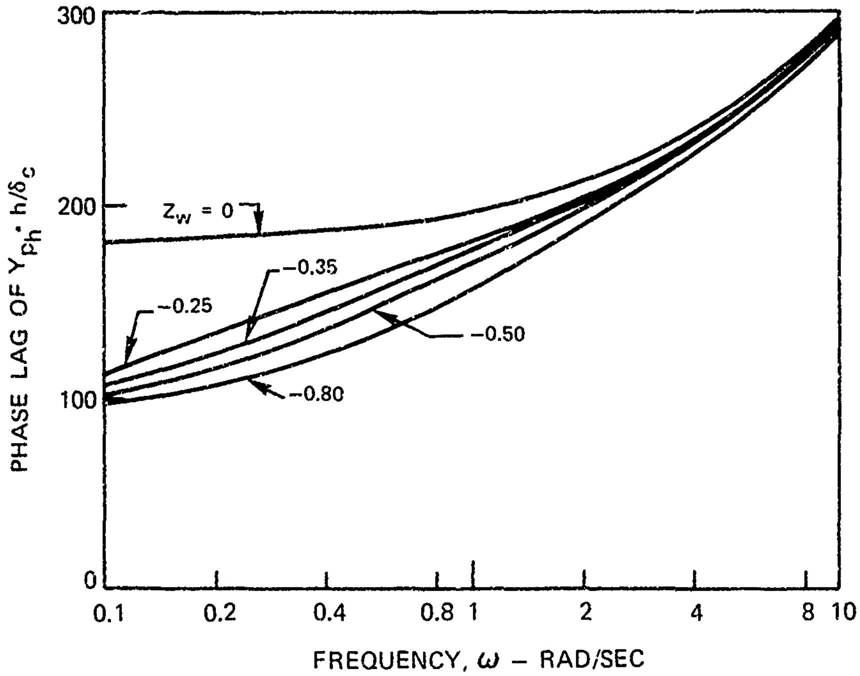


Figure 44. Phase Lags for Pilot-Height Open-Loop Dynamics at Several Z_w Levels

SIMULATOR MODE	FB	MB
SYMBOL	□	■

T/W > 1.15

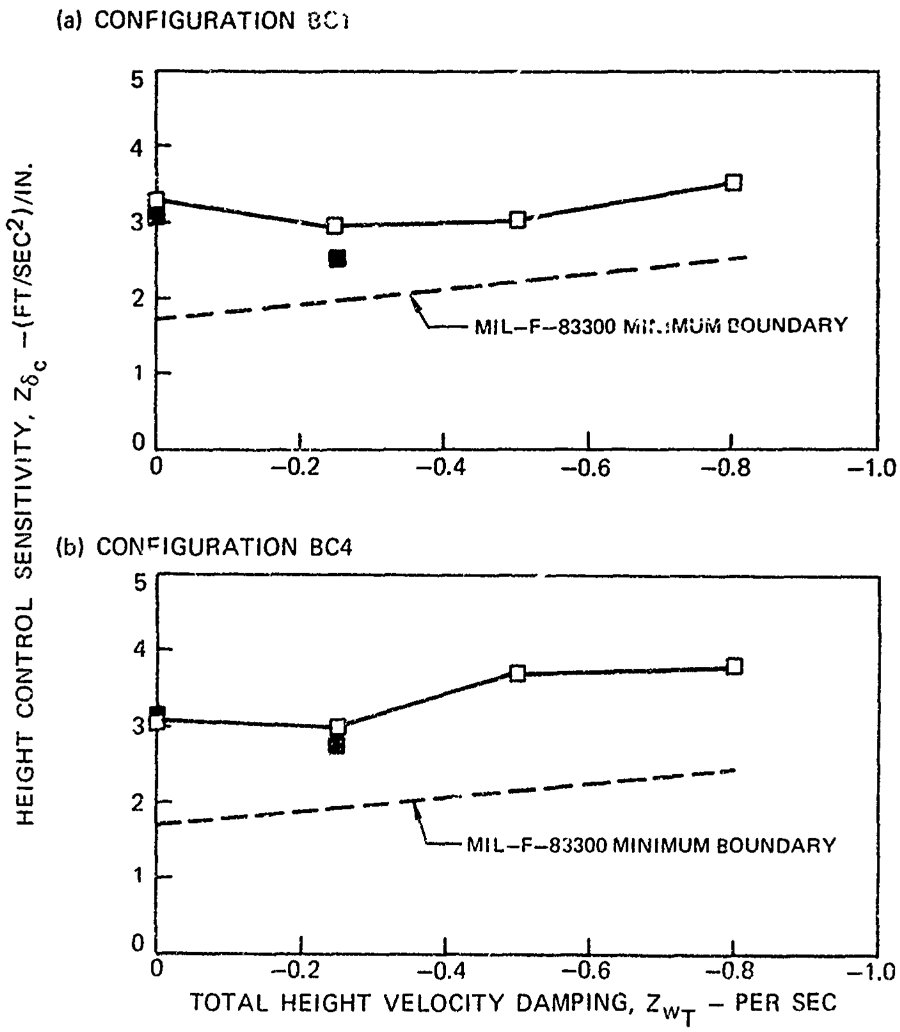


Figure 45. Height Control Sensitivity Results Showing the Effects of Height Velocity Damping

TYPE OF DAMPING	$Z_{w_T} = Z_{w_a} + Z_{w_s}$, $Z_{w_a} = Z_{w_s}$				$Z_{w_T} = Z_{w_a}$, $Z_{w_s} = 0$				$Z_{w_T} = Z_{w_s}$, $Z_{w_a} = 0$			
PILOTS	CALSPAN B*		UARL		CALSPAN B*		UARL		CALSPAN B*		UARL	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	○'	●'	□	■	□'	■'	△	▲	△'	▲'

LEVEL BOUNDARIES FROM MIL-F-83300

Z_{w_T} = TOTAL HEIGHT VELOCITY DAMPING Z_{w_a} = AERODYNAMIC HEIGHT VELOCITY DAMPING Z_{w_s} = SAS HEIGHT VELOCITY DAMPING

*$U_m = 0, \sigma_{u_g} = \sigma_{v_g} = 1.7$ FT/SEC FOR CALSPAN PILOT EVALUATIONS

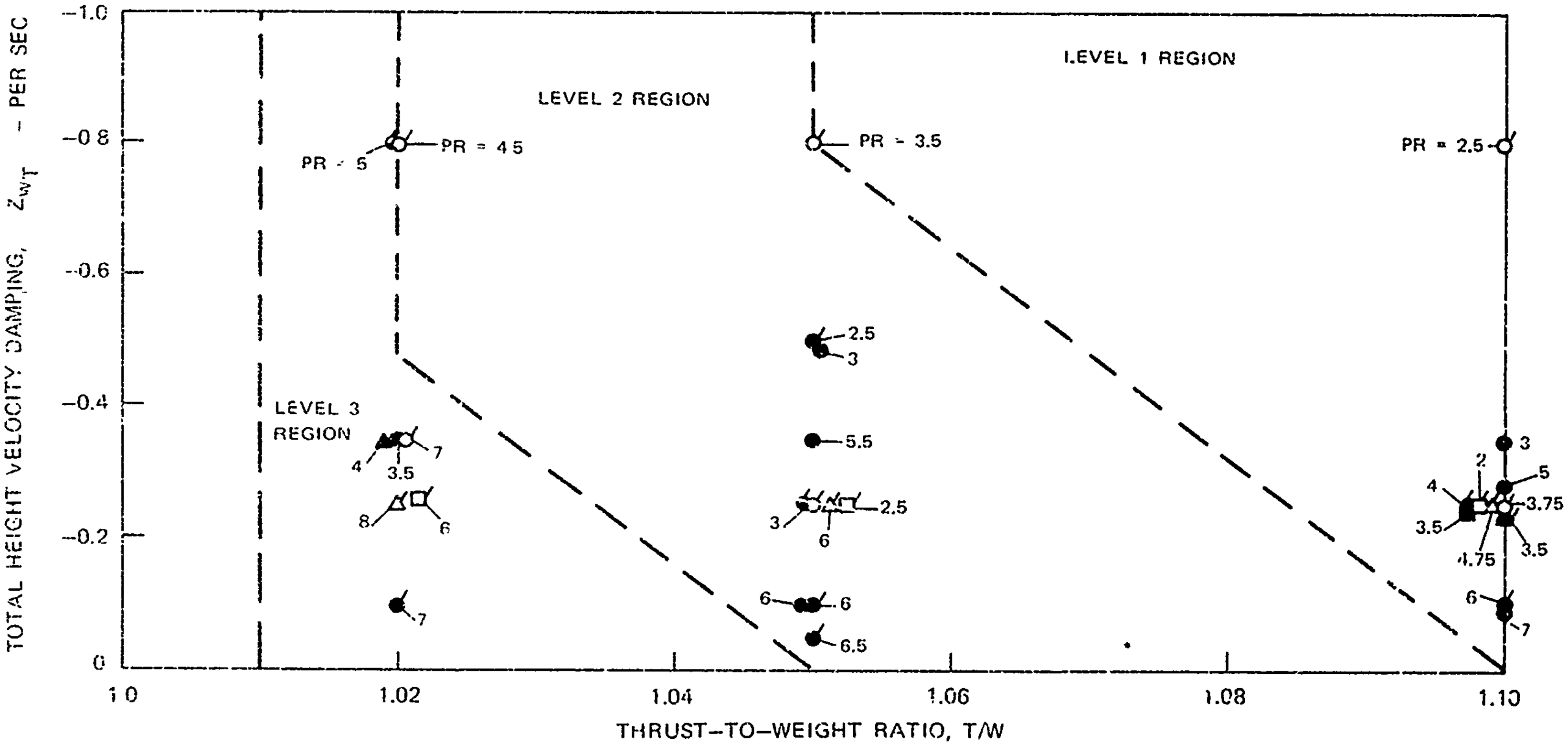


Figure 46. Pilot Rating Results Showing the Interaction Between Height Velocity Damping and Thrust-to-Weight Ratio

T/W	1.02		1.05		1.10	
SIMULATOR MODE	FB	MB	FB	MB	FB	MB
SYMBOL	○	●	□	■	△	▲

CONFIGURATION BC1

$Z_{w_T} = Z_{w_a} + Z_{w_s} = -0.25$ FOR ALL CASES

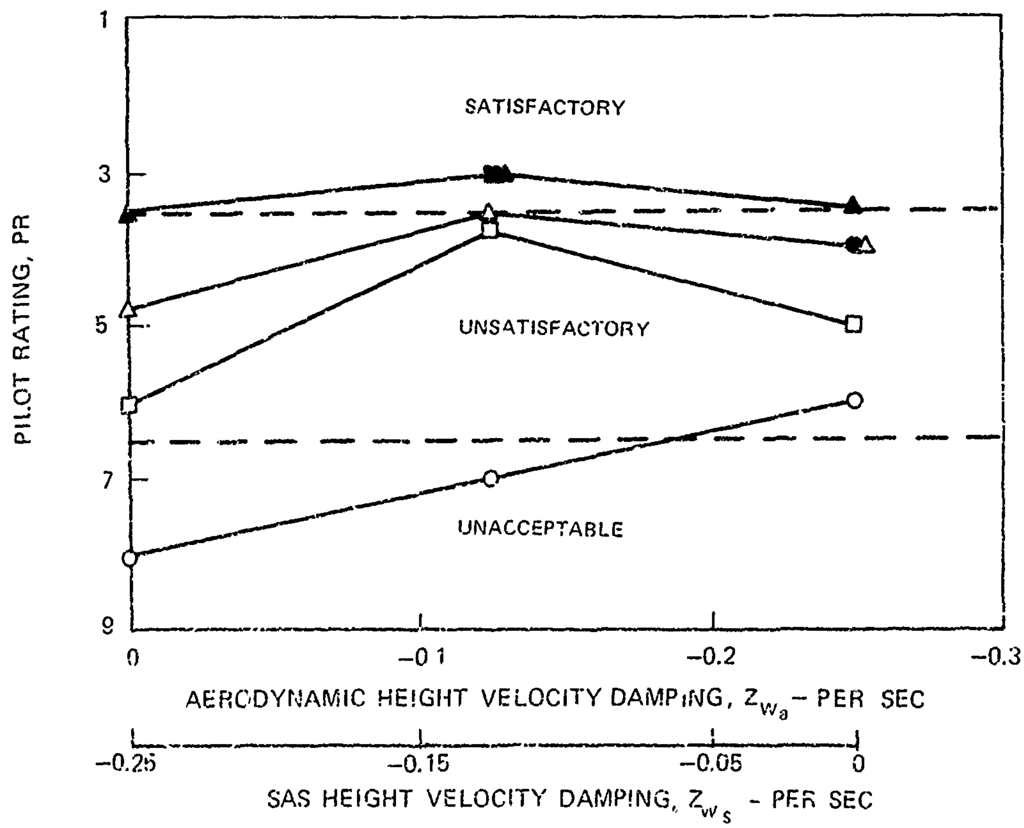


Figure 47. Comparison of Pilot Rating Results for Aerodynamic Versus Stability Augmentation System Height Velocity Damping

LEVEL OF Z_{w_T}	− 0.25		−0.35		− 0.50	
DELAY, d_h	0		0	0.1	0	
SIMULATOR MODE	FB	MB	FB	FB	FB	MB
SYMBOL	○	●	□	□ with tick	△	▲

CONFIGURATION BC1 T/W = 1.05

$Z_{w_T} = Z_{w_a} + Z_{w_s}$ WHERE $Z_{w_a} = Z_{w_s}$

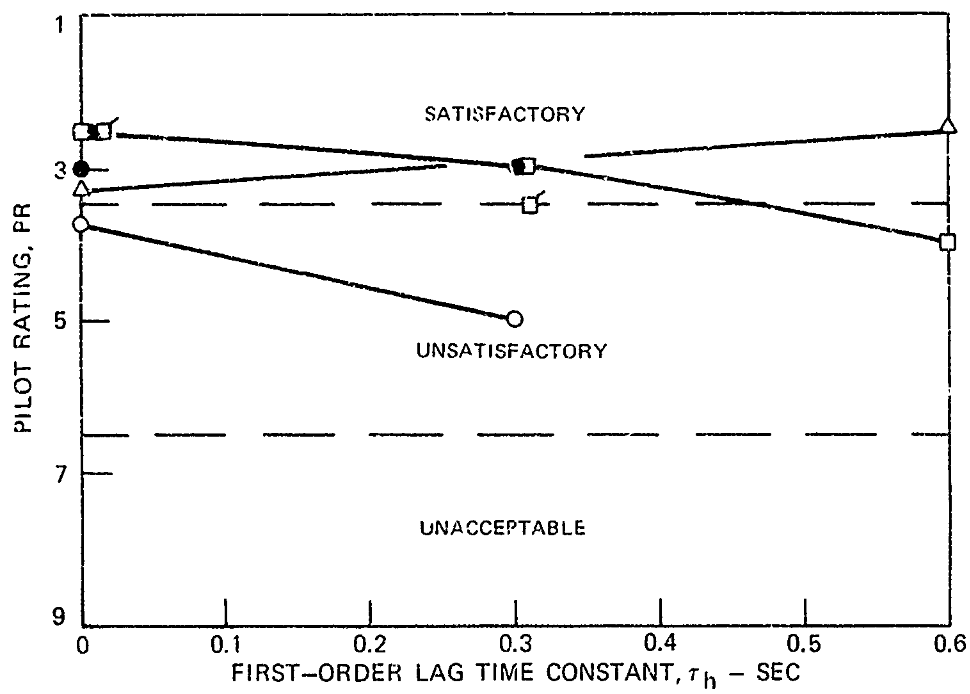


Figure 48. Pilot Rating Results Showing the Interaction Between First-Order Lag Time Constant and Height Velocity Damping

PILOT	B			
ΔT/W	0.13		0.28	
SIMULATOR MODE	FB	MB	FB	MB
SYMBOL	○	●	□	■

CONFIGURATION BC1 $Z_{w_T} = Z_{w_S} = -0.35$ T/W = 1.02

ΔT/W: MAXIMUM THRUST INCREMENT AVAILABLE THROUGH STORED ENERGY

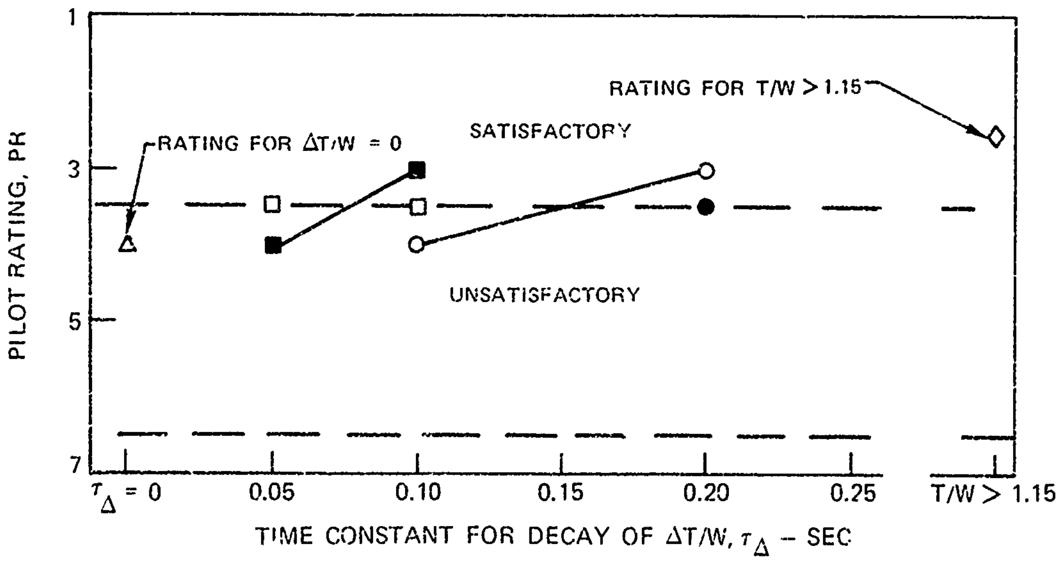


Figure 49. Change in Pilot Ratings Which Results from Incremental Thrust Available Through Stored Energy

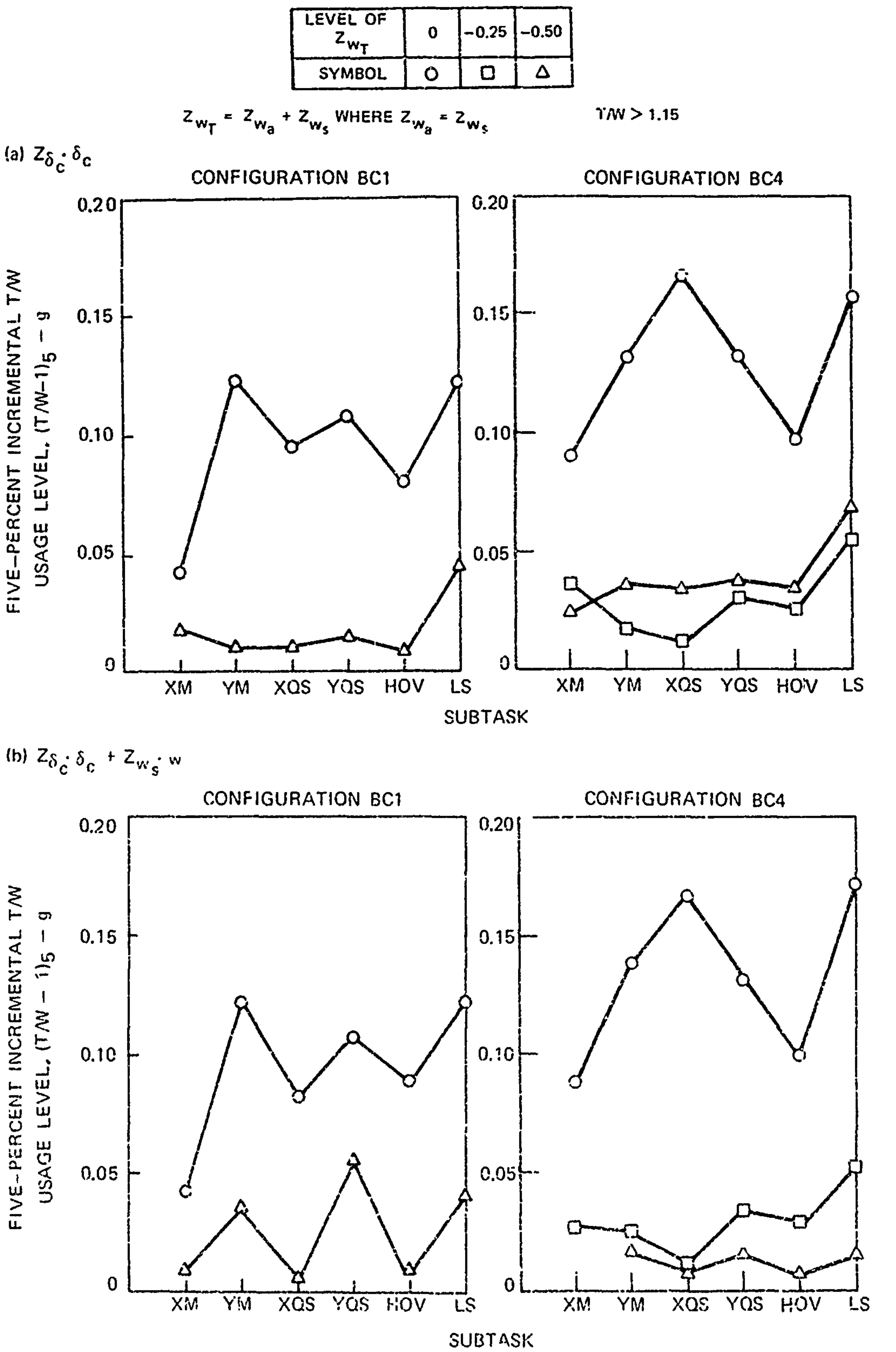


Figure 50. Effect of Z_{w_T} on Incremental Thrust 5-Percent Exceedance Levels, $(T/W-1)_5$, Computed for Increased Thrust Commands

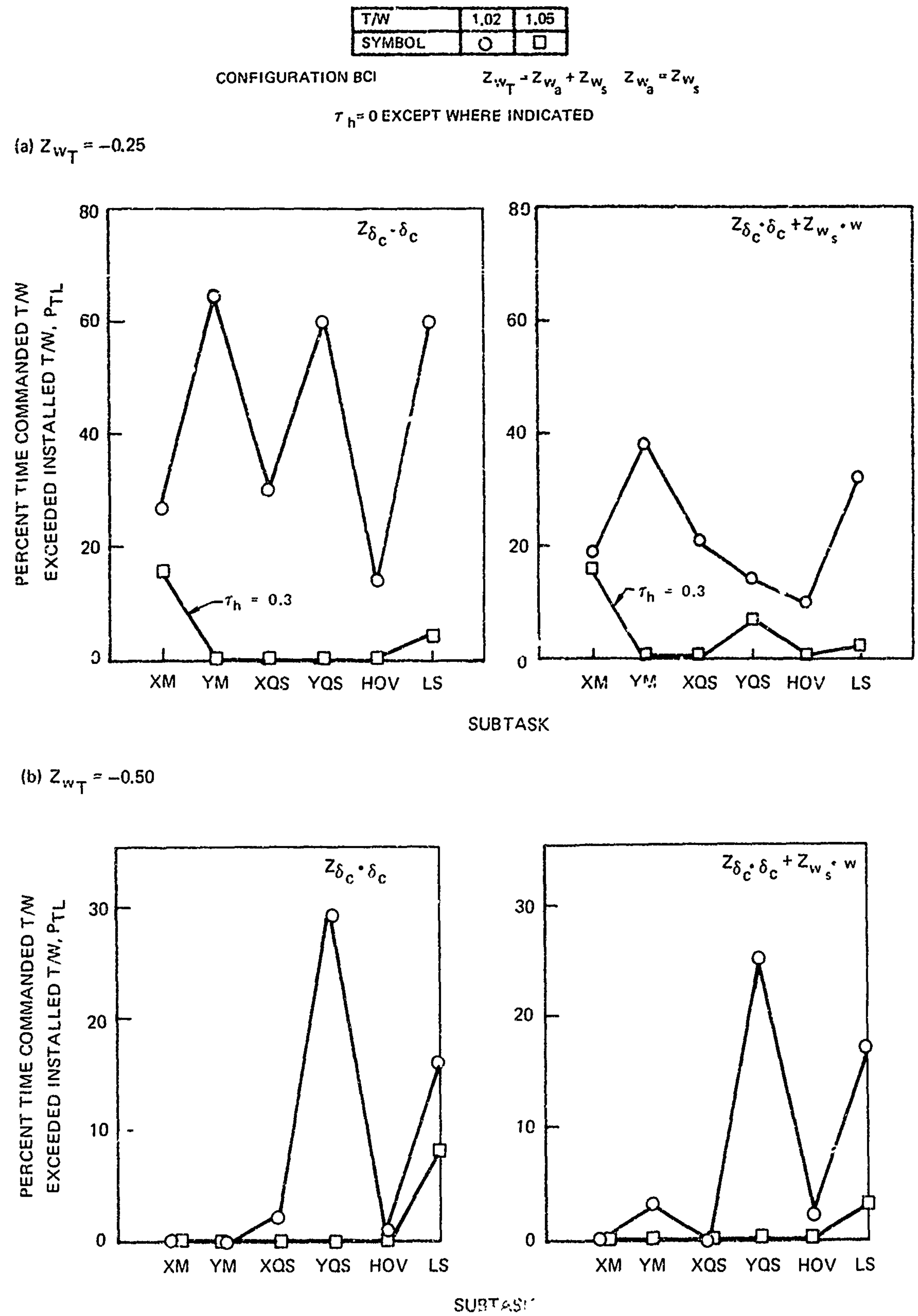


Figure 51. Percent Time Installed Thrust-to-Weight Ratio Limits Exceeded

LAG TIME CONSTANT	0	0.3
SYMBOL	○	□

CONFIGURATION BCI   T/W = 1.10   FIXED BASE

$Z_{w_T} = Z_{w_a} + Z_{w_s} = -0.25$ WHERE $Z_{w_a} = Z_{w_s}$

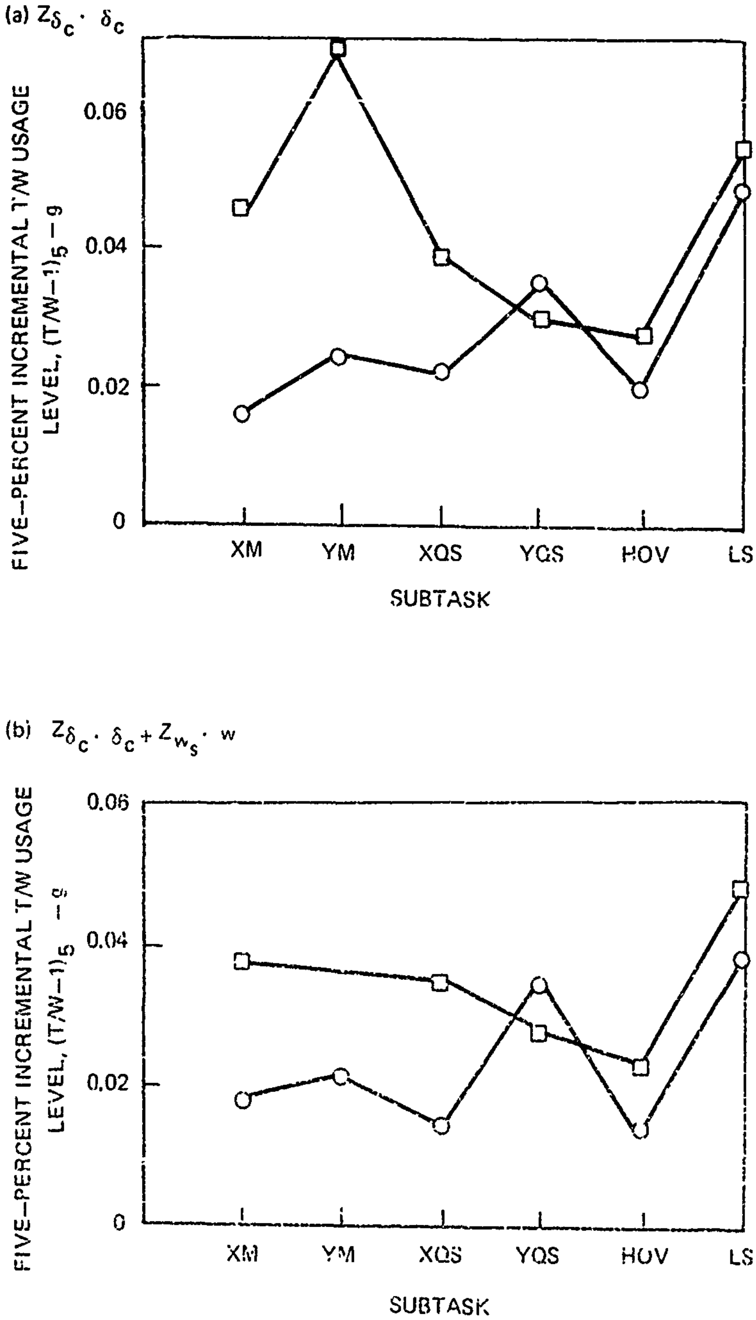


Figure 52. Effect of First-Order Thrust Lags on Incremental Thrust 5-Percent Exceedance Levels Computed for Increased Thrust Commands

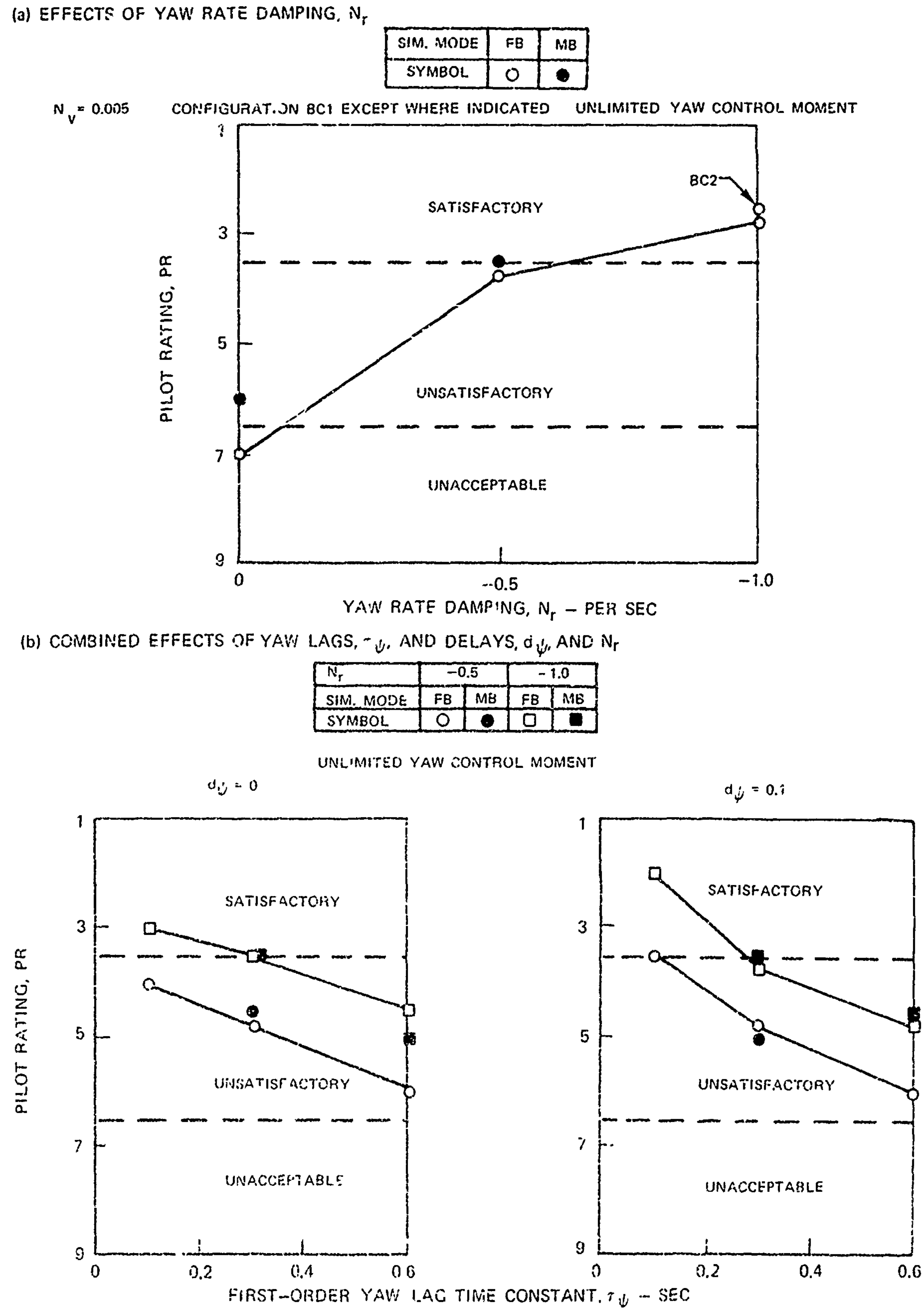


Figure 53. Pilot Rating Results Showing the Effects of Yaw Rate Damping and Lags and Delays in Yaw Control Response

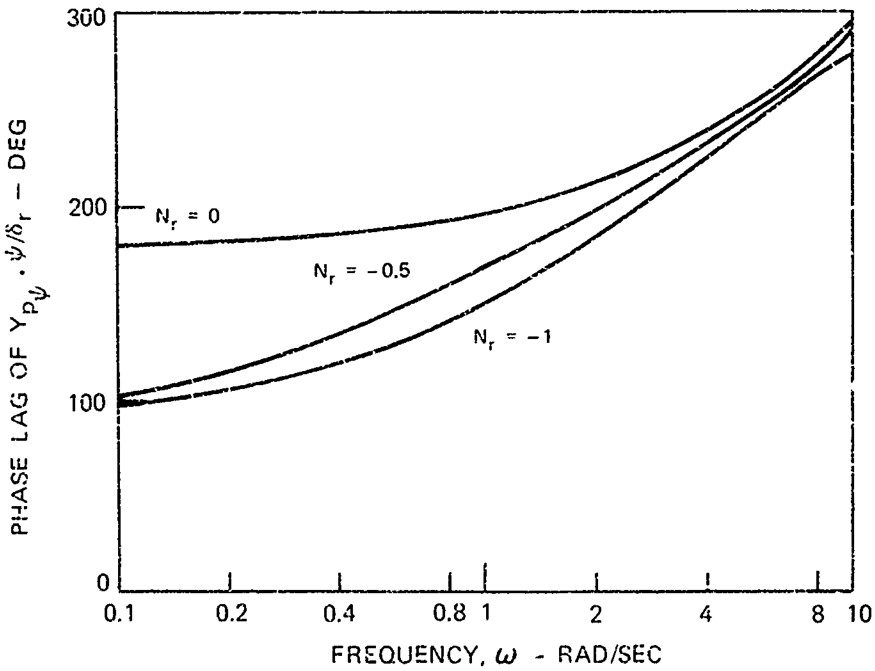


Figure 54. Phase Lag for Pilot-Yaw Open-Loop Dynamics at Several Levels of N_r

N_r	−0.5		−1.0	
SIM. MODE	FB	MB	FB	MB
SYMBOL	○	●	□	■

CONFIGURATION BC1

$\overline{N}_{c_5}$ = 0.10 RAD/SEC^2 = YAW CONTROL MOMENT 5-PERCENT EXCEEDANCE LEVEL WITH UNLIMITED MOMENT AVAILABLE

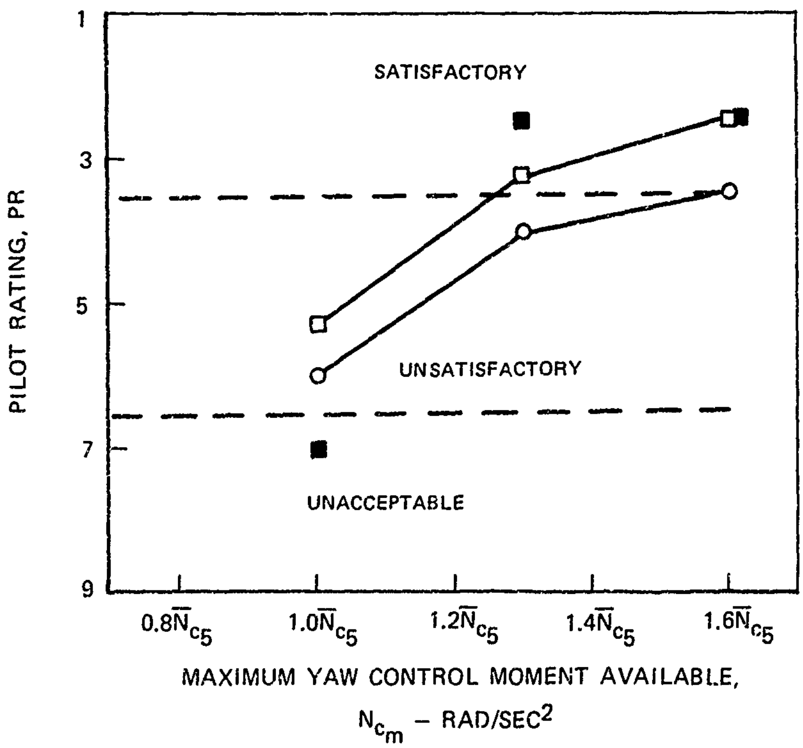


Figure 55. Effects of Yaw Control-Moment Limits on Pilot Rating

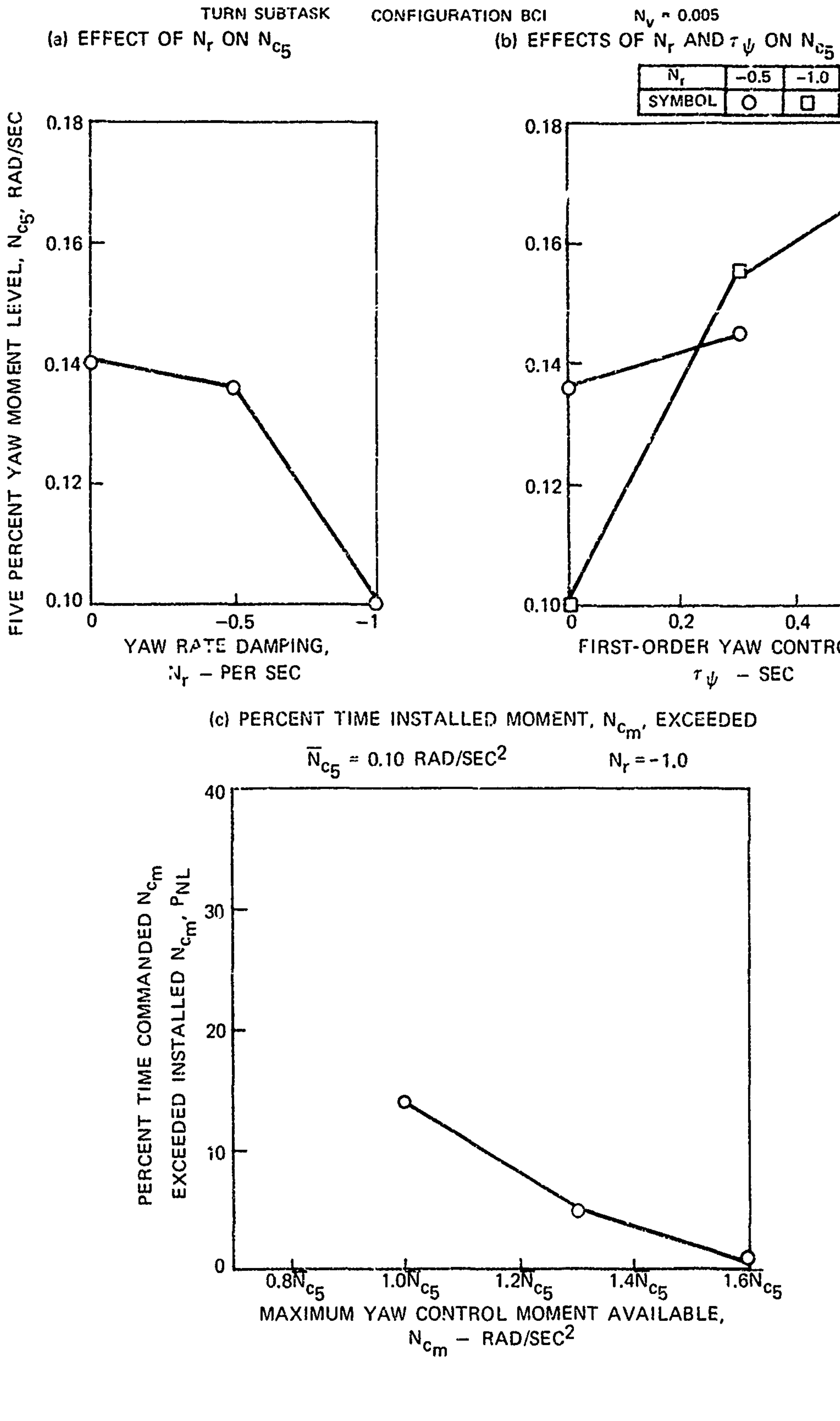


Figure 56. Yaw Control-Moment-Usage Results

APPENDIX A

SUMMARY OF FLYING QUALITIES DATA FROM UARL PILOT EVALUATIONS

This Appendix contains a detailed tabulation of the flying qualities data (pilot ratings and pilot-selected control sensitivities) obtained from the flight simulator evaluations with UARL pilots.

Table A-I identifies the studies conducted in the UARL program and lists the parameters for the cases evaluated in each investigation. It also provides a key to the tables which summarize data in Appendices A, B and C. Tables A-II through A-VIII list results from the longitudinal and lateral control studies in the following sequence: A-II, turbulence effects; A-III, control lags and delays; A-IV, control moment limits; A-V, control moments through stored energy; A-VI, inter-axis motion coupling; A-VII, independent thrust-vector control; and A-VIII, rate-command/attitude-hold control. Flying qualities results from the height control studies are listed in Tables A-IX and A-X as follows: A-IX, velocity damping and thrust-to-weight ratio interactive effects; and A-X, thrust lags and delays and incremental thrust through stored energy. Finally, pilot ratings and pilot-selected sensitivities from the directional control studies are summarized in Table A-XI.

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TABLE A-I

SUMMARY OF PARAMETERS FOR CASES EVALUATED AND KEY TO TABLES SUMMARIZING DATA

P: Indicates Parameter Varied During Study F: Control Sensitivity Fixed

S: Control Sensitivity Selected by Pilot UL: Unlimited

Study	Parameters	Cases	Basic Conf.	Longitudinal[1]							Vertical			Directional				Flying Qualities Results Table No.	Pilot Comments Table No.	Control Moment or T/W Usage Table No.
				M_u	X_u	M_q	M_θ	M_{c_m}	M_{δ_e}	σ_{u_g}[4]	Z_{w_T}	T/W	Z_{δ_c}	N_v	N_r	N_{c_m}	N_{δ_r}			
Effects of Turbulence	$\sigma_{u_g} = \sigma_{v_g}$[2]	T1-T18	BC1	0.33	-0.05	-1.7	-4.2	UL	S	P	-1	1.15	-3.2	0.002	-1	UL	0.20	A-II	B-I	C-I
			BC2	1.0	-0.05	-1.1	-2.5													
			BC3	1.0	-0.05	-2.0	3													
			BC4	1.0	-0.20	-3.0	-1.7													
			BC5	0.33	-0.20	-1.7	-4.2													
			BC6	1.0	-0.20	-1.1	-2.5													
Lags and delays in pitch and roll control	$\tau_e = \tau_a$[3], $d_e = d_a$[3], $\zeta_e = \zeta_a$, $\omega_{n_e} = \omega_{n_a}$	LL1-LL27	BC1 through BC6	Same as T1-T18				UL	S	3.4	-1	1.15	-3.2	0.002	-1	UL	0.20	A-III	B-II	C-II
Pitch, roll and yaw moment limits	$M_{c_m}, L_{c_m}, N_{c_m}$, $\tau_e = \tau_a$, $d_e = d_a$	LM1-LM25	BC1, BC4, BC5, BC6	Same as T1-T18				P	S	3.4	-1	1.15	-3.2	0.002	-1	P	0.20	A-IV	B-III	C-III
Pitch control moment through stored energy	$M_{c_m}, \Delta M_{c_m}, \tau_\Delta$	LS1-LS13	BC1, BC4, BC5, BC6	Same as T1-T18				P[5]	S	3.4	-1	1.15	-3.2	0.002	-1	UL	0.20	A-V	B-IV	Control moment not measured
Inter-axis motion coupling	M_p, L_q, $M_{\delta_a}/L_{\delta_a}$, $L_{\delta_e}/M_{\delta_e}$	LC1-LC8	BC1	Same as T1-T18				UL	S	3.4	-1	1.15	-3.2	0.002	-1	UL	0.20	A-VI	B-V	C-IV
Independent longitudinal thrust-vector control	τ, δ_e, θ_{TS}	LT1-LT15	BC1, BC2, BC4	Same as T1-T18				UL	S	3.4	-1	1.15	-3.2	0.002	-1	UL	0.20	A-VII	B-VI	C-V
Rate command/attitude hold control	$M_q, L_p, M_\theta, L_\phi$, ζ, ω_n	LR1-LR15	BC1	0.33	-0.05	P	P	UL	S	3.4	-1	1.15	-3.2	0.002	-1	UL	0.20	A-VIII	B-VII	C-VI
			BC4	1.0	-0.20	P	P													
Velocity damping and thrust-to-weight ratio effects on height control	Z_{w_a}, Z_{w_g}, Z_{w_T}, T/W	H21-H228	BC1	0.33	-0.05	-1.7	-4.2	UL	F	3.4	P	P	S	0.002	-1	UL	0.20	A-IX	B-VIII	C-VII
			BC4	1.0	-0.20	-3.0	-1.7													
Lags and delays in thrust response	τ_h, d_h	HL1-HL8	BC1	0.33	-0.05	-1.7	-4.2	UL	F	3.4	P	1.05	S	0.002	-1	UL	0.20	A-X	B-IX	C-VII
Incremental thrust through stored energy	$\Delta T/W, \tau_\Delta$	HS1-HS5	BC1	0.33	-0.05	-1.7	-4.2	UL	F	3.4	F	P	S	0.002	-1	UL	0.20	A-X	B-IX	Thrust usage data not measured
Directional control studies	N_r, N_{c_m}, τ_ψ, d_ψ	D1-DC2	BC1	0.33	-0.05	-1.7	-4.2	UL	F	3.4	-1	1.15	-3.2	0.005	P	P	S	A-XI	B-X	C-VIII
			BC2	1.0	-0.05	-1.1	-2.5													

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative. Also, if a longitudinal term is treated as a parameter, the corresponding lateral term is as well.

2. Longitudinal and lateral turbulence levels always equal throughout this program.

3. Pitch and roll control lags always equal. Pitch and roll control delays also always equal.

4. Wind simulation included a mean wind from the north, U_w = 10 kts.

5. Maximum roll moment, L_{c_m}, unlimited.

TABLE A-II

FLYING QUALITIES RESULTS FROM THE STUDY OF THE EFFECTS OF TURBULENCE INTENSITY

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-I

Case	Basic Conf.	Stability Derivatives[1]				Real Root	Complex Roots $-\zeta\omega_n + j\omega_d$	$\sigma_{u_g}{}^2$	$\sigma_{v_g}{}^2$	Pilot	Fixed Base			Moving Base		
		M_{u_g}	X_u	M_q	M_θ						M_{δ_e}	L_{δ_a}	PR	M_{δ_e}	L_{δ_a}	PR
T1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	3.4	3.4	A	0.330	0.308	2.0			
"								"	"	B	0.206	0.304	2.0	0.313	0.242	2.0
T2								5.8	5.8	B	0.268	0.239	2.0			
T3								8.2	8.2	A	0.412	0.358	4.5			
"								"	"	B	0.341	0.306	3.0	0.289	0.221	3.0
T4	BC5	0.33	-0.20	-1.7	-4.2	-0.29	-0.81±j1.85	3.4	3.4	A	0.307	0.205	4.0			
"								"	"	B	0.306	0.248	3.0	0.298	0.243	2.0
T5								5.8	5.8	B	0.358	0.248	3.0			
T6								8.2	8.2	A	0.307	0.365	4.5			
"								"	"	B	0.367	0.291	4.0	0.379	0.291	5.0
T7	BC4	1.0	-0.20	-3.0	-1.7	-2.5	-0.35±j0.64	3.4	3.4	A	0.333	0.331	3.0			
"								"	"	B	0.274	0.225	4.0	0.380	0.301	3.0
T8								5.8	5.8	B	0.452	0.380	3.0			
T9								8.2	8.2	A	0.616	0.388	8.0			
"								"	"	B	0.513	0.434	5.0	0.375	0.297	9.0
T10	BC2	1.0	-0.05	-1.1	-2.5	-0.5	-0.30±j1.47	3.4	3.4	A	0.373	0.320	4.0			
"								"	"	B	0.343	0.350	5.0	0.375	0.297	3.0
T11								5.8	5.8	B	0.416	0.340	6.0			
T12								8.2	8.2	B	0.445	0.362	8.0			
T13	BC6	1.0	-0.20	-1.1	-2.5	-0.65	-0.32±j1.48	3.4	3.4	A	0.342	0.285	4.5			
"								"	"	B	0.298	0.242	5.0	0.320	0.260	6.0
T14								5.8	5.8	B	0.452	0.363	7.0	0.436	0.390	7.0
T15								8.2	8.2	A	0.581	0.352	9.0			
"								"	"	B	0.538	0.442	9.0			
T16	BC3	1.0	-0.05	-2.0	0	-2.2	0.08±j0.68	3.4	3.4	A	0.359	0.427	5.0			
"								"	"	B	0.449	0.419	3.0	0.407	0.280	6.0
T17								5.8	5.8	B	0.439	0.373	6.0			
T18								8.2	8.2	B	0.467	0.352	8.0			

1. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
2. Mean wind, U_m = 10 kts.

TABLE A-III

LONGITUDINAL AND LATERAL FLYING QUALITIES RESULTS FROM THE STUDY OF CONTROL SYSTEM LAGS AND DELAYS

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-II

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots $-\zeta\omega_n \pm j\omega_1$	First-Order Control Lags		Second-Order Control Lags		Control Delays		Pilot	Fixed Base			Moving Base		
		M_{uc}	[illegible]	M_q	M_θ			τ_c	τ_a	ζ_c, ζ_a	$\omega_{n_c}, \omega_{n_a}$	d_c	d_a		σ_{δ_e}	σ_{δ_a}	PR	σ_{δ_e}	σ_{δ_a}	PR
LL1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0.1	0.1	-	-	-	-	B	0.303	0.248	[illegible]			
LL2								0.3	0.3					A	0.294	0.203	3.0			
"								"	"					B	0.330	0.251	2.5			
LL3								0.6	0.6					A	0.355	0.352	2.0			
"								"	"					B	0.339	0.288	3.0	0.372	0.295	5.5
LL4	BC5	0.33	-0.20	-1.7	-4.2	-0.29	-0.81±j1.85	0.1	0.1	-	-	-	-	B	0.302	0.242	2.0			
LL5								0.3	0.3					B	0.296	0.254	2.0			
LL6								0.6	0.6					A	0.241	0.312	3.0			
"								"	"					B	0.430	0.363	4.0	[illegible]	0.262	3.0
LL7	BC4	1.0	-0.20	-3.0	-3.7	-2.5	-0.35±j0.64	0.1	0.1	-	-		-	B	0.424	0.319	2.0	0.418	0.345	4.0
LL8								0.3	0.3					A	0.399	0.349	2.5			
"									"					B	0.319	0.275	3.0	0.421	0.329	5.0
LL9								0.6	0.6					A	0.437	0.328	4.0			
"								"	"					B	0.461	0.404	3.0			
LL10	BC2	1.0	-0.05	-1.1	-2.5	-0.5	-0.30±j1.47	0.1	0.1	-	-	-	-	B	0.409	0.280	4.0	0.390	0.298	5.5
LL11								0.3	0.3					A	0.324	0.25?	5.0			
"								"	"					B	0.347	0.270	5.0	0.424	0.319	7.0
LL12								0.6	0.6					A	0.387	0.393	8.0			
"								"	"					B	0.414	0.374	9.0	0.309	0.310	10.0
LL13	BC6	1.0	-0.20	-1.1	-2.5	-0.65	-0.32±j1.48	0.1	0.1	-	-	-	-	B	0.432	0.348	4.0			
LL14								0.3	0.3					A	0.314	0.193	4.5			
"								"	"					B	0.303	0.257	5.0	0.378	0.328	7.0
LL15								0.6	0.6					B	0.434	0.350	8.0			
LL16	BC3	1.0	-0.05	-2.0	0	-2.2	-0.08±j0.68	0.1	0.1	-	-	-	-	B	0.427	0.351	6.0	0.397	0.337	5.0
LL17								0.3	0.3					A	0.436	0.455	9.0			
"								"	"					B	0.433	0.365	7.0	0.423	0.375	7.0
LL18								0.6	0.6					A	0.595	0.602	10.0			
"								"	"					B	0.422	0.369	7.0			
LL19	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	-	-	0.50	3.33	-	-	B	0.295	0.226	7.0			
LL20										0.22	3.33			B	0.300	0.272	10.0			
LL21										1.00	3.33			B	0.352	0.310	4.0			
LL22										1.00	5.23			B	0.317	0.257	3.0			
LL23	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0	0	-	-	0.1	0.1	B	0.297	0.260	[illegible]	0.307	0.254	2.5
LL24								0.3	0.3			0.1	0.1	B	0.357	0.304	3.0			
LL25[3]								0.3	0.3			0.1	0.1	B	0.332	0.270	5.0			
LL26	BC2	1.0	-0.05	-1.1	-2.5	-0.5	-0.30±j1.47	0	0	-	-	0.1	0.1	B	0.399	0.334	5.0	0.366	0.280	5.5
LL27								0.3	0.3			0.1	0.1	B	0.383	0.334	7.0	0.371	0.317	7.0

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Lag and delay affect both the control and stability augmentation system inputs.

TABLE A-IV

FLYING QUALITIES RESULTS FROM THE STUDY OF PITCH, ROLL AND YAW CONTROL MOMENT LIMITS

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-III

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Maximum Control Moments Available			First-Order Control Lag		Control Delay		Pilot	Fixed Base			Moving Base		
		M_{us}	$Y_{..}$	N_c	M_θ		$-\zeta\omega_n \pm j\omega_d$	M_{c_m}	L_{c_m}	N_{c_m}	τ_e	τ_a	d_e	d_a		M_{δ_e}	L_{δ_a}	PR	M_{δ_e}	L_{δ_a}	PR
LM1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0.360	0.415	0.120	-	-	-	-	B	0.301	0.256	7.0	0.301	0.234	7.0
LM2								0.396	0.457	0.132					A	0.307	0.261	3.0			
"								"	"	"					B	0.296	0.243	2.0	0.317	0.256	3.0
LM3								0.432	0.498	0.144					A	0.240	0.200	2.0			
"								"	"	"					B	0.327	0.278	3.0			
LM4								0.595	0.415	0.120					B	0.337	0.269	3.0	0.303	0.218	2.5
LM5	BC5	0.33	-0.20	-1.7	-4.2	-0.29	-0.81±j1.85	0.300	0.280	0.120	-	-	-	-	B				0.320	0.268	7.0
LM6								0.380	0.360	0.150					A	0.350	0.359	3.0			
"								"	"	"					B				0.297	0.218	2.5
LM7								0.462	0.440	0.182					A	0.270	0.233	3.0			
LM8	BC4	1.0	-0.20	-3.0	-1.7	-2.5	-0.35±j0.64	0.820	0.605	0.175	-	-	-	-	A	0.260	0.194	6.0			
"								"	"	"					B	0.413	0.395	8.0			
LM9								0.902	0.666	0.193					A	0.215	0.244	8.0			
"								"	"	"					B	0.432	0.404	4.5			
LM10								0.984	0.727	0.211					A	0.304	0.261	4.5			
"								"	"	"					B	0.431	0.404	3.0	0.426	0.348	5.0
LM11								1.066	0.788	0.229					B				0.428	0.334	4.5
LM12	BC6	1.0	-0.20	-1.1	-2.5	-0.65	-0.32±j1.48	0.890	0.750	0.170	-	-	-	-	B	0.387	0.351	7.0			
LM13								0.979	0.825	0.187					A	0.215	0.182	10.0			
"								"	"	"					B	0.387	0.351	5.0			
LM14								1.068	0.900	0.204					A	0.228	0.182	8.0			
"								"	"	"					B	0.357	0.353	4.5	0.393	0.325	6.0
LM15								1.157	0.975	0.221					A	0.266	0.259	7.0			
LM16								1.250	1.050	0.288					B				0.400	0.338	5.0
LM17	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0.396	0.457	0.132	0.3	0.3	0.1	0.1	B	0.339	0.264	4.0	0.348	0.290	4.5
LM18								0.432	0.498	0.144	0.3	0.3	0.1	0.1	A	0.233	0.194	4.0			
"								"	"	"	"	"	"	"	B	0.339	0.264	4.0	0.306	0.245	3.0
LM19								0.468	0.540	0.156	0.3	0.3	0.1	0.1	B	0.346	0.275	2.5			
LM20								0.369	0.457	0.132	0.6	0.6	0.1	0.1	B	0.371	0.312	4.5			
LM21								0.432	0.498	0.144	0.6	0.6	0.1	0.1	B	0.384	0.325	4.0			
LM22								0.468	0.540	0.156	0.6	0.6	0.1	0.1	B	0.366	0.297	3.0			
LM23	BC5	0.33	-0.20	-1.7	-4.2	-0.29	-0.81±j1.85	0.420	0.400	0.165	0.6	0.6	0.1	0.1	B	0.368	0.312	4.0			
LM24								0.462	0.440	0.182	0.6	0.6	0.1	0.1	B	0.358	0.323	3.5			
LM25								0.504	0.480	0.199	0.6	0.6	0.1	0.1	B	0.433	0.330	4.0			

1. Standard wind simulation. $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

TABLE A-V

LONGITUDINAL FLYING QUALITIES RESULTS FROM THE STUDY OF INCREMENTAL CONTROL MOMENTS THROUGH STORED ENERGY

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-IV

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots $-\zeta\omega_n \pm j\omega_d$	Control-Moment, Stored Energy Parameters[3]			Pilot	Fixed Base			Moving Base		
		M_{u_g}	X_u	M_q	M_θ			M_{c_m}	ΔM_c	τ_Δ		M_{δ_e}	L_{δ_a}	PR	M_{δ_e}	L_{δ_a}	PR
LS1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	$-0.81 \pm j1.85$	0.356	30%	0.05	B				.254	.192	5.5
LS2								0.356	30%	0.10	A	0.320	0.251	3.0			
"								"	"	"	B	0.300	0.224	5.0			
LS3								0.356	30%	0.20	B	0.303	0.253	4.5	.254	.192	4.0
LS4								0.356	50%	0.20	B	0.297	0.251	2.0			
LS5	BC5	0.33	-0.20	-1.7	-4.2	-0.29	$-0.81 \pm j1.85$	0.300	30%	0.10	B	0.310	0.255	7.0			
LS6								0.340	30%	0.05	B	0.314	0.265	6.0			
LS7								0.340	30%	0.20	A	0.347	0.247	4.5			
"								"	"	"	B	0.308	0.258	4.0			
LS8	BC4	1.0	-0.20	-3.0	-1.7	-2.5	$-0.35 \pm j0.64$	0.902	0	0	B				.371	.333	5.5
LS9								0.902	30%	0.05	B				.381	.342	5.0
LS10								0.902	30%	0.10	A	0.373	0.310	8.0			
"								"	"	"	B	0.401	0.333	5.0			
LS11								0.902	30%	0.20	A	0.291	0.241	7.0			
"								"	"	"	B	0.381	0.294	8.0	.382	.337	4.0
LS12	BC6	1.0	-0.20	-1.1	-2.5	-0.65	$-0.32 \pm j1.48$	0.979	30%	0.10	A	0.246	0.138	9.0			
"								"	"	"	B	0.388	0.340	6.0			
LS13								0.979	30%	0.20	A	0.254	0.134	8.0			
"								"	"	"	B	0.410	0.299	5.0			

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Stored energy effects were only simulated in the pitch axis. Roll and yaw control moments were unlimited.

TABLE A-VI

LONGITUDINAL AND LATERAL FLYING QUALITIES RESULTS FROM THE STUDY OF RATE-COMMAND/ATTITUDE-HOLD CONTROL

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-VII

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Damping Ratio and Natural Frequency		Pilot	Fixed Base			Moving Base		
		M_{ug}	X_u	M_q	M_θ		$-\zeta\omega_n \pm j\omega_d$	ζ	ω_n		M_{δ_e}	L_{δ_a}	PR	M_{δ_e}	L_{δ_a}	PR
LR1	BC1	0.33	-0.05	- 2	- 8	-0.092	-0.98±j2.64	0.35	2.8	B	0.812	[illegible]	[illegible]			
LR2				- 2	-40	-0.058	-1.00±j6.24	0.16	6.3	B	2.408	2.140	[illegible]	3.414	3.498	4.5
LR3				- 4	- 8	-0.093	-1.98±j1.98	0.71	2.8	A	0.944	0.904	6.0			
"				"	"	"	"	"	"	B	0.984	0.884	5.0			
LR4				- 4	-40	-0.058	-2.00±j6.00	0.32	6.3	B	3.640	3.340	2.0			
LR5				- 6	-12	-0.079	-2.99±j1.71	0.87	3.44	B	1.792	1.528	4.0			
LR6				- 6	-40	-0.058	-3.00±j5.57	0.47	6.32	B	2.588	2.208	2.5	4.182	4.698	3.5
LR7				- 8	-40	-0.058	-4.90±j4.90	0.63	6.32	A	3.044	2.420	4.0			
LR8				-10	-50	-0.055	-5.00±j5.50	0.67	7.43	A	3.960	3.344	3.0			
"				"	"	"	"	"	"	B				5.532	6.300	3.0
LR9	BC4	1.0	-0.20	- 2	-16	-0.28	-0.99±j3.87	0.248	4.0	B	1.192	0.864	4.5			
LR10				- 2	-25	-0.26	-0.99±j5.32	0.200	5.0	B	2.152	1.868	5.0			
LR11				- 4	-16	-0.27	-1.97±j3.45	0.500	4.0	B	1.648	1.392	3.5	2.178	2.274	5.0
LR12				- 4	-25	-0.24	-1.97±4.54	0.400	5.0	B	2.584	2.284	3.0			
LR13				- 6	-16	-0.27	-2.97±j2.61	0.750	4.0	B	1.632	1.372	3.0			
LR14				- 6	-26	-0.25	-2.98±j4.06	0.610	5.0	B	2.208	1.912	3.0	3.756	3.792	4.5
LR15				-10	-50	-0.22	-4.99±j5.51	0.670	7.43	A	3.756	3.228	3.0			
"				"	"	"	"	"	"	B				5.010	5.694	3.0

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

TABLE A-VII

LONGITUDINAL FLYING QUALITIES RESULTS FROM THE STUDY OF INDEPENDENT THRUST-VECTOR CONTROL

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-VI

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Thrust Vector Control Parameters			Pilot	Fixed Base			Moving Base		
		M_{u_g}	X_u	M_q	M_θ		$-\zeta\omega_n \pm j\omega_d$	$\dot{\gamma}$[3]	γ_{δ_e}[4]	$\dot{\theta}_{TS}$[4]		M_{δ_e}	L_{δ_a}	PR	M_{δ_e}	L_{δ_a}	PR
LI1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	$-0.81 \pm j1.85$	5	-	-	A	0.329	0.286	2.5			
"								"			B	0.314	0.242	4.0	0.314	0.242	4.5
LI2								10			B	0.314	0.242	4.0			
LI3								20			B	0.329	0.286	3.5	0.314	0.242	3.0
LI4	BC4	1.0	-0.20	-3.0	-1.7	-2.5	$-0.35 \pm j0.64$	5	-	-	B	0.329	0.286	4.5	0.329	0.286	5.5
LI5								10			B	0.329	0.286	4.5			
LI6								20			A	0.329	0.286	5.0			
"								"			B	0.329	0.286	3.5	0.329	0.286	4.0
LI7	BC2	1.0	-0.05	-1.1	-2.5	-0.5	$-0.30 \pm j1.47$	5	-	-	B	0.338	0.335	5.0			
LI8								10			A	0.329	0.384	6.5			
"								"			B	0.314	0.242	4.5			
LI9								20			B	0.338	0.335	4.0	0.338	0.335	5.5
LI10[5]	BC1	0.33	-0.05	-1.7	-4.2	-0.13	$-0.81 \pm j1.85$	20	-	-	B	0.314	0.242	4.0			
LI11								-	2	1	B	N.A.[6]	0.242	3.5			
LI12								-	5	1	B	"	0.242	3.0			
LI13								-	10	1	B	"	0.242	3.5			
LI14	BC4	1.0	-0.20	-3.0	-1.7	-2.5	$-0.35 \pm j0.64$	-	5	1	B	N.A.[6]	0.286	10.0			
LI15	BC2	1.0	-0.05	-1.1	-2.5	-0.5	$-0.30 \pm j1.47$	-	5	1	B	N.A.[6]	0.335	10.0			

1. Standard gust simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Thrust-vector thumb-switch control, conventional attitude control.
4. Thrust-vector control with stick, thumb-switch attitude control.
5. Thrust-vector angle displayed on instrument panel only.
6. Not applicable - see γ_{δ_e} for longitudinal thrust rotation control sensitivity.

TABLE A-VIII

LONGITUDINAL AND LATERAL FLYING QUALITIES RESULTS FROM THE STUDY OF INTER-AXIS MOTION COUPLING

Vertical and Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-V

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Motion Coupling Parameters				Pilot	Fixed Base			Moving Base		
		M_{u_g}	X_u	M_q	M_θ		$-\zeta\omega_n \pm j\omega_1$	M_p	L_q	$M_{\delta_a}/L_{\delta_a}$	$L_{\delta_e}/M_{\delta_e}$		M_{δ_e}	L_{δ_a}	PR	M_{δ_e}	L_{δ_a}	PR
LC1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.83	2	-2	0	0	A	0.385	0.342	4.0			
"								"	"	"	"	B	0.359	0.293	3.5	0.349	0.291	3.5
LC2								4	-4	0	0	A	0.386	0.356	6.5			
"								"	"	"	"	B	0.376	0.323	4.5			
LC3								0	0	0.25	-0.25	B	0.362	0.299	3.0			
LC4								0	0	0.50	-0.50	A	0.362	0.308	2.5			
"								"	"	"	"	B	0.322	0.283	3.5	0.264	0.321	2.5
LC5								2	-2	0.25	-0.25	A	0.313	0.290	4.0			
"								"	"	"	"	B	0.316	0.284	4.5	0.310	0.360	4.0
LC6								4	-4	0.50	-0.50	B	0.412	0.358	7.5			
LC7	BC2	1.0	-0.05	-1.1	-2.5	-0.5	-0.30±j1.47	2	-2	0.25	-0.25	B	0.442	0.373	6.5			
LC8								2	-2	-0.25	0.25	B	0.446	0.399	6.5			

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

TABLE A-IX

HEIGHT CONTROL FLYING QUALITIES RESULTS FROM THE STUDY OF THE INTERACTION BETWEEN HEIGHT VELOCITY DAMPING AND THRUST-TO-WEIGHT RATIO

Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-VIII

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Height Damping, Thrust-to-Weight Parameters			Pilot	Fixed Base		Moving Base	
		M_u	X_u	M_q	M_θ		$-\zeta_h\omega_h \pm j\omega_h$	Z_{w_a}	Z_{w_s}	T/W		Z_{δ_c}	PR	Z_{δ_c}	PR
HZ1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0	0	UL	A	3.46	9.0		
"								"	"	"	B	3.14	7.0	3.03	7.0
HZ2								-0.125	-0.125	UL	A	2.98	4.0		
"								"	"	"	B	3.12	4.5	2.57	4.0
HZ3								-0.25	-0.25	UL	A	3.04	3.0		
HZ4								-0.40	-0.40	UL	A	3.50	2.0		
HZ5								-0.05	-0.05	1.02	B			3.05	7.0
HZ6								-0.125	-0.125	1.02	A	3.0	7.0		
HZ7								0	-0.25	1.02	A		8.0		
HZ8								-0.25	0	1.02	A		6.0		
HZ9								0	-0.35	1.02	B			3.0	4.0
HZ10								-0.25	-0.25	1.02	A		4.0		
HZ11								-0.40	-0.40	1.02	A		5.0		
"								"	"	"	B		4.0	2.98	5.0
HZ12								-0.025	-0.025	1.05	B			3.07	6.5
HZ13								-0.05	-0.05	1.05	B			3.01	6.0
HZ14								-0.125	-0.125	1.05	A		3.0		
"								"	"	"	B		4.5	2.62	3.0
HZ15								0	-0.25	1.05	A		6.0		
HZ16								-0.25	0	1.05	A		5.0		
HZ17								-0.25	-0.25	1.05	A		4.0		
"								"	"	"	B		2.5	3.06	2.5
HZ18								-0.40	-0.40	1.05	A		3.5		
HZ19								-0.05	-0.05	1.10	B			3.24	6.0
HZ20								-0.125	-0.125	1.10	A		2.5		
"								"	"	"	B		4.5	2.62	3.0
HZ21								0	-0.25	1.10	A		4.5		
"								"	"	"	B		5.0	2.82	3.5
HZ22								-0.25	0	1.10	A		4.0		
"								"	"	"	B			2.76	3.5
HZ23								-0.25	-0.25	1.10	A		2.5	.	
"								"	"	"	B		4.0		
HZ24								-0.40	-0.40	1.10	A		2.5		
HZ25	BC4	1.0	-0.20	-3.0	-1.7	-2.5	-0.35±j0.64	0	0	UL	A	3.0	10.0		
"								"	"	"	B	3.02	8.0	3.06	8.0
HZ26								-0.125	-0.125	UL	A	2.60	5.0		
"								"	"	"	B	3.28	4.5	[illegible].70	4.5
HZ27								-0.25	-0.25	UL	A	3.71	3.0		
HZ28								-0.40	-0.40	UL	A	3.52	3.0		

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts, no vertical gusts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Total height velocity damping, $Z_{w_T} = Z_{w_a} + Z_{w_s}$

TABLE A-X

HEIGHT CONTROL FLYING QUALITIES RESULTS FROM THE STUDIES OF CONTROL LAGS AND DELAYS AND INCREMENTAL THRUST THROUGH STORED ENERGY

Directional Parameters Listed in Table A-I
Pilot Comments Given in Table B-IX

(a) Control Lags and Delays

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Parameters					Pilot	Fixed Base		Moving Base	
		M_{u}	X_u	M_q	M_θ		$-\zeta\omega_n \pm j\omega_d$	Z_{w_a}[3]	Z_{w_s}[3]	T/W	τ_L	τ_Δ		Z_{δ_c}	PR	Z_{δ_c}	PR
HL1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	-0.12[illegible]	-0.1[illegible]5	1.05	0.3	0	A	3.0	[illegible]		
"								-0.125	-0.125	1.0[illegible]	0.3	0	B	↓	[illegible].5	[illegible].01	3.0
HL2								-0.175	-0.17[illegible]	1.05	0	0.1	A	↓	[illegible].5		
HL3								-0.17[illegible]	[illegible]	1.05	0.3	0	A	↓	3.0		
"								"	"	"	"	"	B	↓	3.0		
HL4								-0.175	-0.175	1.05	0.3	0.1	A	↓	3.5		
HL5								-0.175	-0.175	1.05	0.6	0	A	↓	4.5		
"								"	"	"	"	"	B	↓	3.5		
HL6								0	-0.35	1.05	0.6	0	B	↓	4.0		
HL7								-0.25	-0.25	1.05	0.6	0	A	↓	2.5		

(b) Incremental Thrust Through Stored Energy

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Roots	Parameters					Pilot	Fixed Base		Moving Base	
		M_{u_g}	X_u	M_q	M_θ		$-\zeta\omega_n \pm j\omega_d$	Z_{w_a}[3]	Z_{w_s}[3]	T/W	$\Delta T/W$	τ_Δ		Z_{δ_c}	PR	Z_{δ_c}	PR
HS1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0	-0.35	1.02	0	0	B			2.67	4.0
HS2								0	-0.35	1.02	0.13	0.10	B	3.0	4.0		
HS3								0	-0.35	1.02	0.13	0.20	B	↓	3.0	2.68	3.5
HS4								0	-0.35	1.02	0.28	0.10	B	↓	3.5	2.67	3.0
HS5								0	-0.35	1.02	0.28	0.05	B	↓	3.5	2.67	4.0

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, U_m = 10 kts, no vertical gusts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Total height velocity damping, $Z_{w_T} = Z_{w_a} + Z_{w_s}$

TABLE A-XI

DIRECTIONAL CONTROL FLYING QUALITIES RESULTS

Vertical Parameters Listed in Table A-I
Pilot Comments Given in Table B-X

Case[1]	Basic Conf.	N_v	Stability Derivatives[2] N_{u_g}	X_u	N_q	N_θ	Real Roots	Complex Roots $-\zeta\omega_n \pm j\omega_1$	Damping, Lag, Delay and Moment Limit Parameters N_r	N_{c_r}	τ_ψ	d_ψ	Pilot	Fixed Base N_{δ_r}	Fixed Base PR	Moving Base N_{δ_r}	Moving Base PR
D1	BC1	0.005	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	0	UL	0	0	B	0.20[illegible]	[illegible]	0.208	[illegible].0
D2									-0.5		0	0	A	0.2[illegible]5	4.0		
"									"		"	"	B	0.255	3.5	0.229	3.5
D3									-1.0		0	0	A	0.28[illegible]	3.0		
"									"		"	"	B	0.2[illegible]	2.5		
D4	BC2	0.005	1.0	-0.05	-1.1	-2.5	-0.50	-0.70±j1.47	-1.0	UL	0	0	B	0.312	2.5		
D5	BC1	0.005	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	-0.5	UL	0.3	0	A	0.20[illegible]	4.0		
D6									-0.5		0	0.1	B	0.270	3.5		
D7									-0.5		0.3	0	A	0.273	4.5		
"									"		"	"	B	0.181	5.0	0.259	4.5
D8									-0.5		0.3	0.1	A	0.235	4.0		
"									"		"	"	B	0.280	5.5	0.226	5.0
D9									-0.5		0.6	0	B	0.252	6.0		
D10									-0.5		0.6	0.1	B	0.248	6.0		
D11									-1.0		0.1	0	B	0.306	3.0		
D12									-1.0		0	0.1	B	0.294	2.0		
D13									-1.0		0.3	0	A	0.341	3.0		
"									"		"	"	B	0.313	4.0	0.275	3.5
D14									-1.0		0.3	0.1	A	0.258	3.0		
"									"		"	"	B	0.305	4.5	0.270	3.5
D15									-1.0		0.6	0	A	0.271	4.0		
"									"		"	"	B	0.237	5.0	0.258	5.0
D16									-1.0		0.6	0.1	A	0.308	4.0		
"									"		"	"	B	0.300	5.5	0.284	4.5
D17	BC1	0.005	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.85	-0.5	0.10	0	0	B	0.238	6.0		
D18									-0.5	0.13	0	0	B	0.238	4.0		
D19									-0.5	0.16	0	0	B	0.233	3.5		
D20									-1.0	0.10	0	0	A	0.288	5.0		
"									"	"	"	"	B	0.305	5.5	0.295	7.0
D21									-1.0	0.13	0	0	A	0.236	3.0		
"									"	"	"	"	B	0.306	3.5	0.294	2.5
D22									-1.0	0.16	0	0	A	0.287	3.0		
"									"	"	"	"	B	0.306	2.0	0.294	2.5

1. Standard wind simulation $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.
2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

APPENDIX B

SUMMARY OF PILOT COMMENTS FROM UARL PILOT EVALUATIONS

This Appendix presents edited pilot comments for the flight simulator test cases evaluated by UARL pilots. The comments are tabulated for each case according to the subtasks performed by the pilots. For each subtask, comments were solicited according to the questionnaire shown in Table IV. Pilots also made additional comments as they felt necessary.

The comment tables parallel the flying qualities data tables of Appendix A. That is, for each data table in Appendix A there is a corresponding comment table in Appendix B. The comments from the longitudinal and lateral control studies are summarized in Tables B-I through B-VIII as follows: B-I, turbulence effects; B-II, control lags and delays; B-III, control-moment limits; B-IV, control moments through stored energy; B-V, inter-axis motion coupling; B-VI, independent thrust-vector control; and B-VII, rate-command/attitude-hold control. Pilot comments for the height control test cases are summarized in Tables B-VIII and B-IX. Table B-VIII contains velocity damping and thrust-to-weight ratio. Comments from the studies of thrust lags and delays and incremental thrust through stored energy are shown in Table B-IX. The pilot comments from the directional control studies are summarized in the last table, B-X.

TABLE B-I

PILOT COMMENTS FROM THE STUDY OF TURBULENCE INTENSITY

Flying Qualities Results Given in Table A-II

Case	Conf. Parameters	Pilot-Sim. Mod.	[illegible]	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
T1	B1 $\sigma_{u_g}=\sigma_{v_g}=$ 3.4 ft/sec	A-F3	0.330 0.206	2	Set to achieve desired roll and pitch response for maneuvering.	Gust effects negligible, could perform the air taxi with considerable precision. Pilot workload quite low. Control motions were very small and low frequency.	Performed quite easily but required a little anticipation to stop at desired point.	Quite easy, required virtually no thrust trim control.	Hover performance very good, required very little pilot effort.	A very good configuration, little control compensation and effort required to perform the task.
		B-F3	0.206 0.304	2	Selected based on maneuvering and hovering requirements.	Pitch is very easily controlled, don't notice any effects of turbulence. Can initiate motion easily in both lateral and longitudinal direction and can stop precisely.	Can stop quickly but fairly large attitude changes are required. No problem holding altitude and heading for my quick stops.	Able to remain over the spot quite well. No problem holding attitude.	Could hover quite accurately. Vertical landing was reasonably precise. Dynamics for one axis didn't affect my evaluation of another axis.	In general, the configuration has no objectionable features.
		B-M3	0.313 0.242	2	Selected to get necessary attitude response.	No problem, could perform this very accurately, very precisely.	Could perform accurately.	Could remain very precisely over the spot and turn quite rapidly while doing so. Wing tilt control was used to small extent.	No problem. Could be done quite precisely. No interaction between dynamics.	No objectionable features in this case, except possibly the low drag parameter, fine attitude characteristics.
T2	BC1 $\sigma_{u_g}=\sigma_{v_g}=$ 3.8 ft/sec	B-F3	0.268 0.239	2	Sensitivity selected primarily for hover	No difficulty, could stabilize and hold my velocities and stop precisely.	Could stop quite quickly and hold my maneuvering position after stopping. More drag would be desirable.	Could turn over a spot quite accurately.	Not difficult. Could hold hover position accurately while performing the vertical landing.	Thought this was a good case
T3	BC1 $\sigma_{u_g}=\sigma_{v_g}=$ 8.2 ft/sec	A-F3	0.412 0.358	4.5	Set to offset gust effects on pitch and roll	Had to anticipate stopping point due to low drag. Somewhat difficult to stop. Effect of moderate gust disturbances on attitude and low translational drag necessitated considerable pilot compensation	Requires considerable anticipation to stop.	Relatively easy but did notice gust disturbances in both position and attitude. Little wing tilt was required.	Performance was good, but it did require some concentration to offset the gust disturbances.	Most objectionable features were moderate gust effects on pitch and roll and the difficulty in stopping
		B-F3	0.341 0.306	3	Selected for precision hover and close control because of relatively high level of turbulence	Somewhat difficult to stabilize desired velocities because of the turbulence. Some problems stopping precisely and hovering. Could perform this part of the task fairly well, though.	No real problems with the quick stop.	Slightly difficult because of the gusts. Good attitude characteristics helped	Precision hover is moderately difficult, must pay attention to gusts and make appreciable attitude changes. Able to land the ship precisely	Good configuration with a moderate workload.
		B-M3	0.250 0.221	3	Set to get the attitude response I desired	Not difficult, good response to all the control inputs. Large speed stability had mixed effects, sometimes blown laterally when maneuvering longitudinally.	No problem, can stop very quickly.	Difficult but again attitude control very nice giving me time to concentrate on position	Could hover quite well, but large X_u, Y_v kept me busy. Could land well. No problem	Drag parameters objectionable. Blown about while maneuvering, made it somewhat difficult to hover and turn-over-a-spot. Had to be pretty adept with my trim button when performing the turn over-a-spot.
T4	[illegible] $\sigma_{u_g}=\sigma_{v_g}=$ 3.? ft/sec	A-F3	0.307 0.205	2	Set mainly for attitude changes during maneuvering.	Somewhat difficult to initiate translational motion, requires rather large attitude changes. Can stop with pretty good degree of precision.	Difficult to perform, just time to get up to speed and then large attitude changes are required to arrest velocity.	Requires trim changes with the wing. Also can get blown around a lot in position. Requires quite a lot of attention	Fairly easy, although the winds push one around in position. Landing and takeoff not difficult.	Biggest objection is high drag of aircraft and the associated large attitudes required to maneuver.
		B-F3	0.306 0.268	3	Selected primarily to control hovering position	Fine response to control inputs. Able to initiate motion and hold desired velocities without problem. Aircraft somewhat sluggish in position response	Couldn't stop as quickly as would like. Somewhat difficult to initiate motion. Excessive attitude changes not really required.	Able to remain over spot fairly well, in spite of the large Y_v. Good attitude dynamics only.	Could hover precisely without any difficulty and perform vertical landing precisely. No interaction effects noticeable.	Only moderately objectionable features were effects of the large X_u in hover and turn-over-a-spot. Favorable features were the good dynamics and the position damping.
		B-M3	0.27? 0.?43	4	Selected to get control over attitude.	Easy to control. Likes the drag parameter, helped to stop nicely. Attitude was well damped.	Could stop quickly, attitude very easy to control and the drag parameter helped to stop.	Can do accurately, if time is taken. Used wing tilt often	Could hover precisely and land without too much difficulty. No interaction on the dynamics.	Drag parameters made turn maneuver somewhat difficult. Favorable features were good attitude stability and position damping.
T5	B5 $\sigma_{u_g}=\sigma_{v_g}=$ 5.2 ft/sec	A-F3	0.?58 0.?40	3	Selected to provide proper attitude rates for hover	Good response to control inputs. Able to initiate and hold motion very nicely. No problem stopping precisely and hovering at the corners.	Can't stop as quickly as would like. Somewhat difficult to build up the speeds.	Able to remain over the spot fairly well. Attitude control is pleasant but large drag parameter caused problems. Used trim a great deal.	Could hover precisely although were relatively large position disturbances from gusts. Could control hover adequately for vertical landing. No interaction between dynamics	Only objectionable feature was turbulence acting on large drag parameters during hover and turn-over-a-spot maneuver.
T6	[illegible] $\sigma_{u_g}=\sigma_{v_g}=$ 8.2 ft/sec	A-F3	0.?37 0.305	4.5	Set primarily for trim during maneuvering.	Attitude control very good, little gust disturbances on attitude. Requires large attitude changes to get desired velocity, but can stop fairly precisely. Gusts push the aircraft around in position.	Control inputs rather large but stopping no problem.	Difficult only because the gusts push the aircraft around in position. Large wing tilt trim changes are required	Performance not too good because of gust disturbance of position. Some difficulty landing. Control activity relatively low frequency	Gust effects on position are objectionable. Attitude well damped.
		B-F3	0.?67 0.?9?	5	Selected to give desired attitude response in hover.	Sluggish position response. Attitude control very nice. Tended to lose position in axis normal to maneuver direction.	Could stop quickly but difficult to hold position after stopping.	Able to perform this maneuver well. Good attitude characteristics significant help.	Somewhat difficult because of large gust effects on drag parameters. Had to make large, rapid attitude changes. No noticeable interaction between axes.	Objectionable feature was turbulence acting on large drag parameters. Attitude control very acceptable. Had to be careful with trim during my turns.

TABLE B-I (Continued)

Case	Drag Parameters	Piloting Mode	δ_e / δ_a	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
T6	BC5 $\sigma_{u_g}=\sigma_{v_g}=$ 8.2 ft/sec	B-MB	0.375 / 0.291	5	Selected to enable control of gusts	Quite difficult, would get blown off laterally when maneuvering longitudinally and vice versa. Motion was initially disorientating because it was chiefly linear motion with little attitude motion because of dynamics.	Could stop as quickly as would like but aircraft too responsive to position gusts	Difficult, must do it very, very slowly. Used a lot of wing tilt. Requires concentration.	Couldn't hover particularly accurately. Could arrest position motion, but very difficult to get back to desired hover position. Could land alright, but it was difficult. Used the trim control to kill velocities. No problem with secondary dynamics.	Gusts acting on large drag parameters very objectionable. Attitude well damped, easy to control, however.
T7	BC4 $\sigma_{u_g}=\sigma_{v_g}=$ 3.4 ft/sec	A-FB	0.333 / 0.332	3	Selected for maneuvering and to control mild gust disturbances.	Response to control inputs good. Stopping at desired point required a little anticipation in reverse roll. Could maintain ground track fairly well.	No problems generating velocity. Stopping required some anticipation	Only problem was effect of mean wind which required small changes in wing tilt, must concentrate to perform the turn.	Performance very good with little control motion required. Landing no problem.	Configuration fairly good. Gust disturbances on roll and pitch did require a bit of pilot attention.
		B-FB	0.274 / 0.225	4	Selected to enable pilot to move the aircraft around in position.	Control response good. Could stabilize and hold velocities and stop precisely. Some difficulty in initiating motion.	No problem, could stop quite quickly. Attitude was easy to control.	Most difficult subtask. The large drag parameters resulted in large position disturbances. Used large trim changes and had to be very careful with them.	Precision hover and vertical landing not difficult. The lateral (longitudinal) drag parameter affected me when trying to control longitudinal (lateral) position.	Major objectionable feature was the effect of winds on the large drag parameters. Favorable feature was that attitude control was quite good.
		B-MB	0.380 / 0.301	3	Selected to overcome attitude damping and enable pilot to change attitude rapidly enough to counteract the effects of drag parameter.	Could maneuver quite accurately. Easy to stop at the corners because of the large drag parameter and low gusts.	Easy to stop very quickly, the drag parameters helped.	Difficult, but was done slowly and seemed to be able to handle it pretty well. Used a lot of wing-tilt angle.	Could hover fairly precisely. Gust disturbances low. Could land quite well. Secondary dynamics no problem either.	Objectionable features-possibly the effects of drag parameter in the turn-over-a-spot annoying. Favorable features-good attitude response, generally low response to the turbulence and the drag parameters helped the maneuvering and quick stop.
T8	BC4 $\sigma_{u_g}=\sigma_{v_g}=$ 5.6 ft/sec	B-FB	0.452 / 0.350	5	Selected to achieve the desired attitude response.	Good attitude response, but the ship was kind of sluggish. Could stabilize and hold velocities and stop precisely.	Could stop quite quickly. Relatively large attitude changes were required.	Most difficult of all the subtasks because of the concentration and activity required to counteract the mean winds acting through the speed-stability parameter and hold my hovering spot.	Moderately difficult, substantial disturbances in position, large attitude changes required to correct them. No interaction	Objectionable feature - attitude response to gusts through speed stability which lead to large position disturbances. Favorable features - good attitude dynamics.
T9	BC4 $\sigma_{u_g}=\sigma_{v_g}=$ 8.2 ft/sec	A-FB	0.616 / 0.366	8	Set to control very large gust disturbances	Difficult to initiate motion, hold heading and stop precisely because of gust effects.	Difficult to stop because of gust effects. Large attitude changes required to control position.	Difficult to hold position. Great deal of coordination between wing tilt and control input required. Difficult to perform.	Difficult, require excessive amounts of control input. Large attitude changes result from gusts and control inputs.	Most objectionable feature was the very high gust sensitivity and lack of attitude damping. Very high workload and very high degree of concentration required to maintain control.
		B-FB	0.513 / 0.434	5	Selected to handle turbulence effects on attitude and to correct for the large position displacements introduced by turbulence.	Effects of turbulence on attitude and position were significant, had to work hard to hold desired velocities. Difficult to maintain the y position while performing the x part of the maneuver and vice-versa. Large control deflections required periodically.	Could stop quickly but had to watch position carefully afterwards. Rapid control motions required.	Able to remain over the spot because of good attitude dynamics. Even with a large Y_v can hover over the spot reasonably well. Had to be careful, used the trim button a good deal.	Attitude dynamics good, allowed pilot to hover fairly well. Biggest problem was effect of turbulence on the drag parameters, made vertical landing difficult. No noticeable interaction.	Objectionable features-effects of turbulence on attitude and position. Favorable features - Good attitude control response.
		B-MB	0.375 / 0.297	9	Selected to overcome gust effects on attitude.	Blown all over, sharp rough gust inputs, attitude oscillates around wildly. Can't perform well	Attitude control workload overwhelming because of gusts. Precise control impossible.	Blown off position by the large gusts, could not change wing tilt quickly enough to hold it. Hands full just controlling pitch, roll attitude.	Couldn't hover precisely, could keep only within ±15 ft of square. Landing hazardous, very difficult, large interactive effects between pitch and roll.	Very difficult to control and hazardous. Needs more damping to reduce response to turbulence.
T10	BC2 $\sigma_{u_g}=\sigma_{v_g}=$ 3.4 ft/sec	A-FB	0.373 / 0.320	4	Set to control gust disturbances on roll and pitch attitude.	No problem initiating or stopping motion. Could remain within the ground track fairly accurately and hold heading and altitude fairly well.	No particular problem, except constant trim had to be held in to maintain velocities.	Performance good, very little wing tilt trim required. Most of the workload from controlling attitude disturbances.	Good performance.	Dynamics were fairly good, more pitch rate and roll rate damping desirable to reduce response to turbulence.
		B-FB	0.343 / 0.350	5	Selected to gain control over attitude	Disagreeable attitude response to control inputs. Difficult to stabilize attitude which also affected my ability to stabilize maneuvering velocities. Could stop fairly precisely but this excited undesired and excessive attitude motions.	Could perform quick stops without great difficulty. Attitude motions were larger than would like.	Difficult to control roll attitude for this subtask.	Could hover fairly precisely and could control hover position sufficiently well to perform a reasonable landing. Attitude dynamics in roll affected my ability to control pitch and vice-versa	Most objectionable feature was the lack of attitude damping.
		B-MB	0.375 / 0.297	5		Not too difficult. Did get blown off track, but not frequently. Gust effects significant on pitch and roll.	No significant problems. Drag parameters small which made it somewhat difficult to arrest motion.	Not too difficult because attitude damping sufficient. Noticeable gust effects on attitude, though.	Can hover precisely and did a good job landing. Some interaction between pitch and roll control.	Objectionable feature was the gust effect on attitude. More damping desirable to reduce gust response. Favorable features - the low drag parameters made the hovering and turn subtasks less difficult.

TABLE B-I (Continued)

Case	Type of Parameters	[illegible]	ζ_θ / ζ_ϕ	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
T11	RC2 $\sigma_{u_g}=\sigma_{v_g}=$ 5.8 ft/sec	B.FB	0.416 / 0.340	6	Selected to control attitude response to gusts and to overcome the lack of damping.	Attitude needs more damping. Turbulence really buffeted me about. Able to stabilize and hold velocities fairly well, but required a great deal of attention. Could stop precisely.	Can stop quickly, but very large attitude changes result. Have some difficulty stabilizing attitude.	Able to remain over the spot quite well. Low drag parameters helped. Attitude required a significant amount of attention	Could hover adequately with effort and could land alright. Attitude wasn't as controllable as it should be. Some interaction between the motion in one axis and my ability to control another axis.	Primary objectionable feature was the lack of attitude damping and its response to turbulence. Favorable feature low drag parameters helped in hover and turn.
T12	RC2 $\sigma_{u_g}=\sigma_{v_g}=$ 0.2 ft/sec	B.FB	0.445 / 0.322	5	Selected to control attitude gust response and control response	Difficult to initiate and hold velocities because of the attitude characteristics, could not maneuver laterally and hold longitudinal position precisely. Attitude seemed unpredictable.	Could stop relatively quickly but had difficulty holding desired position of the other axis. Large attitude changes involved in this subtask.	Able to maintain position fairly well because of low drag parameters. Attitude control quite difficult.	Able to hover fairly well but large attitude excursions involved. Very difficult to accomplish vertical landing. Pitch attitude control definitely affected my ability to control roll and vice-versa.	Attitude characteristics quite objectionable, springy characteristic annoying. Favorable feature - low drag parameters
T13	RC6 $\sigma_{u_g}=\sigma_{v_g}=$ 3.4 ft/sec	A.FB	0.342 / 0.295	4.5	Set to counteract gust disturbances on attitude.	Considerable effort required to control attitude gust disturbances. Large attitude changes necessary to initiate and sustain motion. Difficult to hold desired velocities, but could stop precisely	Difficult to generate velocity. Could stop fairly well, although large attitude changes were required.	Gust disturbances on attitude and position annoying, but performance not too bad. Required concentration.	Performance pretty good, but considerable stick activity due to attitude and position gust disturbances. Landing not too difficult	Needs attitude damping and high drag objectionable in hover, although it did provide translational damping
		B.FB	0.295 / 0.242	5	Selected to control position disturbances and for maneuvering	Difficult because attitude was underdamped. Could not maintain a precise attitude angle or a steady velocity. Could stop fairly precisely.	Difficult to attain velocities, but could stop quickly.	Difficult, had to be very careful with my control inputs and concentrate. Used trim almost constantly	Could hover fairly accurately. Would like better control over attitude for landing. Lateral drag parameter did affect ability to control longitudinally and vice-versa.	The objectionable features were the large drag parameters and the low damping levels in pitch and roll.
		R.MZ		6	Selected to control attitude response to stick inputs and gusts.	Not too difficult, lack of attitude damping affects ability to maintain constant velocity. Lateral speed-stability effects very evident through motion	Can accomplish, but could use more attitude damping	Very tough, large attitude motions. Have to concentrate too much on pitch and roll to turn precisely.	Can hover well but must pay attention. Motion helps to keep from overcontrolling. Can land adequately.	Motion leads to use of smaller, more precise control inputs. Take-off and landing simulations very realistic.
T14	SY $\sigma_{u_g}=\sigma_{v_g}=$ 5.8 ft/sec	B.FB	0.457 / 0.363	7	Selected to get pitch and roll attitude under control	Need more damping in both pitch and roll. Difficult to initiate motion and to hover at the corners. Couldn't hold ground track well.	Can stop quickly but large attitude changes result. Difficult to control attitude	Can't remain over the spot well. Must use wing tilt a great deal. Large pitch and roll angles	Precision hover is manageable, but large attitude angles required. Landing tough because of gusts. Longitudinal dynamics made it difficult to control lateral and vice-versa	Objectionable feature - the lack of damping
		A.MS	0.432 / 0.300	7	Selected to get attitude under control.	Acceleration response to control inputs. Gust response in attitude and position a major annoyance. Couldn't really control precisely	Could stop fairly quickly. Large drag parameter helped. Develops large attitude angles, though.	Could hold position fairly well, but very difficult task. Must do slowly, use wing tilt constantly.	Could hover without too much difficulty. Lot of attitude motion. Landed alright but had to use wing tilt. Some interaction.	Primary objectionable features - large gust inputs, low damping, gusts acting on the drag parameter. Favorable features - none.
T15	RC6 $\sigma_{u_g}=\sigma_{v_g}=$ 8.2 ft/sec	A.FB	0.581 / 0.352	9	Selected to counteract very large gust disturbances and to maintain control	All aspects of the subtask extremely difficult. Primary effort was in maintaining control. Difficult to stay within boundaries of maneuvering area and to hold heading and altitude	Very difficult to perform	Difficult to hold position, height and desired turn rate because of large gust disturbances on pitch and roll	Impossible. Excessive pilot control activity required. Landing hazardous because of difficulty in holding both position and level attitude.	
		B.FB	0.530 / [illegible]	9	Selected to achieve control over attitude and attenuate gust responses	Disagreeable response to control inputs and gusts, needs much more damping. Tough to initiate, stabilize velocities and difficult to stop	Can stop quickly, but uses large attitudes. Large rapid control motions used also.	Able to remain over a spot but required much effort and attention. Used trim almost constantly. Attitude control was difficult	Periodically blown off position and large attitude angles required to arrest motion. Dynamics aren't adequate for vertical landing. The dynamics from longitudinal axis did affect my control of lateral axis, and vice versa	Objectionable features of large gust responses in position and attitude and the small levels of damping. No favorable features
T16	[illegible] $\sigma_{u_g}=\sigma_{v_g}=$ 3.4 ft/sec	A.FB	0.456 / 0.407	5	Set to counteract annoying gust effects	Could be performed with considerable concentration. Pitch and roll were slightly underdamped. Could stop fairly well and hover at desired points.	Performed fairly well but must control gust effects	Some difficulty holding position. Required concentration to perform. Could stop fairly well on preselected heading	Could perform hover with fair precision, required concentration	Lack of roll and pitch damping objectionable.
		B.FB	0.446 / 0.407	4		Could perform fairly well. Would prefer more damping in both pitch and roll. Had to concentrate more with attitude than desirable	Required more concentration and attention to perform than would prefer. No large attitude oscillations	Turned accurately over the spot. Low drag parameters helped. Developed some disagreeably large attitudes.	Hovered quite accurately but required concentration. Vertical landing not too difficult. No real interaction.	Objectionable features - lack of damping in pitch and roll oscillations, response to turbulence more than would like. Favorable features: the low drag parameter

TABLE B-I (Concluded)

Case	Ref. Parameters	Pilot- Rtg. Mode	$\frac{\delta_e}{\delta_a}$	PR	Pilot Comments					
					Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
T16	SC3 $\sigma_{u_g}=\sigma_{v_g}=$ 3.4 ft/sec	B-MB	0.407 0.280	6	Selected to overcome lack of damping and control response to turbulence.	Required a significant amount of control activity. Had to maneuver slowly. Lack of position damping annoying.	Need large attitude changes to stop. Had to roll out at just the right moment to stop and stabilize position. Need position damping.	Could perform fairly well because of the low drag parameters. Had to be careful, however.	Could hover fairly well, but attitude motion required attention. Vertical landing not too difficult. Dynamics from one horizontal axis did affect the other	Objectionable features - low attitude damping, little more drag parameter needed.
T17	SC3 $\sigma_{u_g}=\sigma_{v_g}=$ 5.8 ft/sec	B-FB	0.439 0.373	6	Selected to overcome lack of damping.	Good position response. Difficult to control attitude, tended to overshoot desired angle, required significant compensation.	Could stop quickly but really had to watch attitude. Some tendency to drift off longitudinally when maneuvering laterally.	Able to remain over the spot because of the small drag parameters. Needed large stick inputs, developed some very large pitch and roll rates.	Could hover quite well, but lots of pitch and roll motion. Couldn't hold position precisely during the landing. Pitch dynamics do affect ability to control roll.	Objectionable features - the low level of attitude damping. Favorable features - the small drag parameters.
T15	SC3 $\sigma_{u_g}=\sigma_{v_g}=$ 8.2 ft/sec	B-FB	0.467 0.352	8	Selected to control attitude gust response.	Disagreeable control response inputs. Needs damping in pitch and roll. Difficult to stabilize, hold velocities and stop precisely.	Can stop quickly, but large attitude changes required. Takes some time to stabilize attitude after coming to a stop.	Able to remain over the spot fairly well because drag parameters were small. Attitude control difficult, had to concentrate.	Could hover fairly well but large control motions required, must concentrate. Difficult to maintain position during vertical landing. Dynamics for roll did affect pitch control and vice-versa.	Lack of attitude damping very objectionable. Difficult to control gust response. However, drag helped in the turn-over-a-spot and hover subtasks.

TABLE B-II

PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL AND LATERAL CONTROL SYSTEM LAGS AND DELAYS

Flying Qualities Results Given in Table A-III

Case	Conf. Parameters	Pilot-Sim. Mode	ζ_{d_e} / ζ_{d_a}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
111	BC1 $\tau_e = \tau_a = 0.1$	B-FB	0.303 0.248	2	Selected to get the attitude response wanted.	Not difficult. Nicely damped attitude response, able to select and stabilize velocities with no problem, stop precisely. No lags evident in the attitude response.	Not difficult to perform one control attitude quite precisely. One perform this task very well.	Not difficult to perform. Wing tilt control not used much.	No problem, can hover quite precisely with very little control input. Vertical landing also no difficulty.	Fine case. Attitude is very nicely correlated with the stick inputs, no noticeable lags, can control quite well.
112	BC1 $\tau_e = \tau_a = 0.3$	A-FB	0.294 0.208	3	Set to achieve desired attitude response for the air taxi.	Performance was good, only slightly objectionable feature was that commanding an attitude change caused slight oscillation, also slight lag in attitude response. Gust effects minimal, control motions low frequency and small in amplitude.	Performance was good, although slight lag in attitude response when commanding rapid attitude changes.	Very easy and very little thrust rotation control required.	Hover required very little effort, performance good.	Only slightly objectionable feature was small lag in attitude response and small oscillatory motion when commanding a rapid attitude change.
		B-FB	0.330 0.251	2.5	Selected to get the attitude response to overcome a slight lag.	Air taxi not difficult. Could perform precisely. Some slight oscillation when rolling or pitching in and out of maneuver, but nothing difficult to attenuate. No lack of control power.	Could perform precisely, no problem. Again slight oscillation of pitch and roll, but easily damped.	Quite easy to perform. Didn't use wing tilt control much.	Relaxed inputs in hover, could hover quite precisely. Vertical landing also not difficult.	Nicely damped, low response to turbulence, lag effects small, some slight tendency to oscillate in pitch and roll but easily damped.
113	BC1 $\tau_e = \tau_a = 0.6$	A-FB	0.355 0.352	2	Selected to give desired attitude response.	The air taxi relatively easy. Response to control inputs good about all axes. Easy to initiate maneuver although some anticipation required to stop at a desired position. Could stop and hold hover with good degree of precision. Only small attitude changes required.	No problem, although some position anticipation required to stop at desired point.	Relatively easy. Had to use a small amount of wing tilt control to offset the mean wind effects.	Very easy to hover, required only very small control inputs.	Liked the good attitude control and the very low response to turbulence. Pilot workload quite low.
		B-FB	0.339 0.288	3	Selected to get the attitude response.	Air taxi no problem. Could perform both X and Y maneuver tasks precisely and hold velocities steady and arrest motion without too much difficulty. Slight tendency to oscillate at the end of maneuvers, had to compensate for this but it wasn't difficult.	Could stop quite accurately and didn't experience any real large attitude changes. Again, some tendency to oscillate in pitch and roll, had to worry about this a bit.	No difficulty here. Could perform quite well. Wing tilt control wasn't used a great deal.	Could hover very precisely with relaxed slow control motions. Vertical landing easy to perform.	Little bit of oscillation in pitch and roll but not a big problem. Nice relaxed response, low response to turbulence, nicely damped configuration.
		B-MB	0.379 0.288	3	Selected to control response to turbulence and also pitch oscillations.	Couldn't perform air taxi as precisely or as easily as desired. Difficult to control attitude and to hold a desired velocity. Could not stop very precisely.	Same problem as air taxi, just couldn't seem to control position rates as accurately as desired.	Some problems were controlling position while turning. Did try to use the wing tilt control, but lost position.	Hover wasn't too great a problem because didn't introduce large control inputs. Didn't get into any oscillations. Could land alright. Some interaction between pitch and roll.	The oscillatory response in pitch and roll annoying. Could not seem to stabilize pitch and roll particularly well while maneuvering and doing quick stops.
114	BC3 $\tau_e = \tau_a = 0.1$	B-FB	0.302 0.242	2	Selected to give desired response.	Good response to control inputs, very predictable attitude response, no problems at all in coming up to a desired velocity and holding it and stopping at desired position. Liked the large drag parameter here. Didn't worry too much about being blown about.	Could stop very quickly and precisely. Had no problem stabilizing on rate.	Attitude so easily controlled and gusts low enough so that even with high drag didn't have difficulty.	No problem in hover. Occasionally would get blown off position some, but no real difficulty.	No real objectionable features. The large drag made it somewhat difficult to attain lateral and longitudinal velocities. Good attitude response, drag made it easy to stop precisely and rapidly. This is a good case.
115	BC3 $\tau_e = \tau_a = 0.3$	B-FB	0.296 0.254	2	Selected to get the response for roll and pitch.	Could perform air taxi very well. Attitude was well damped, very predictable and no oscillations. Could stop accurately due to the fairly large drag. Gusts no annoyance. Very good case.	Could stop quite precisely, no problems. Large drag helped stopping.	Performed this subtask very well. Could take eyes off attitude and look at wing tilt indicator with no problem. Could tilt the wing rapidly, this compensated very nicely for the mean wind.	Hover no problem, nor was vertical landing.	No objectionable features. Because of good attitude characteristics the high drag was no problem when performing the turn.
116	BC3 $\tau_e = \tau_a = 0.6$	A-FB	0.241 0.312	3	Selected to get adequate attitude response.	Relatively good position control during air taxi but required relatively large attitude changes to get aircraft response in translation. Could hover fairly well at the corners and could hold heading and altitude accurately because workload in pitch and roll was low. Control deflections were small.	Very easy to perform because of the high drag of the configuration.	Difficult in that considerable wing tilt control had to be used to offset the mean wind effects, but with anticipation performance was fairly good.	Hover was fairly good although with the high drag got pushed around in position quite often. This degraded my rating slightly.	The only objectionable feature was the large disturbances in position through the drag of the aircraft while hovering.
		B-FB	0.437 0.363	4	Selected to gain the attitude response needed to overcome lags.	Could perform air taxi fairly well. Did notice that when maneuvering laterally tended to get blown off somewhat in longitudinal position, but handled maneuver fairly well. Some fairly small oscillations in attitude that were difficult to damp, but no great problem.	No problem with this task, could come to desired spot and stop fairly accurately. Rather large drag helped.	Did this quite well. Attitude was sufficiently well damped and controllable that could switch vision between wing tilt angle and display.	With rapid wing tilt could rotate thrust quickly so as to keep fairly decent control over hover position. Vertical landing no problem.	Only objectionable feature was small lag in response but that led to low level oscillations which were fairly persistent and required some attention. Well damped attitude response, low response to turbulence and the large drag helped in maneuvering and quick stops.

TABLE B-II (Continued)

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{M_{\delta_e}}{L_{\delta_a}}$	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Turn-Over-a-Spot	Pilot Comments: Precision Hover, Vertical Landing, Secondary Dynamics	Pilot Comments: Overall Evaluation
116	3C5 $\tau_\theta = \tau_\phi =$ 0.6	B-FB	0.308 0.262	3	Selected to get desired response in pitch and roll.	Could perform air taxi quite precisely. Attitude very well damped, very predictable. Could stop precisely and control hover and maneuvering velocities very well. Had a small problem getting blown off desired track occasionally but that was fairly easy to correct.	No problem. Could perform these quite smoothly and accurately.	Could remain over the spot very well. Did use wing tilt control a good deal because of the high drag.	Hover not difficult. Had to watch the gusts though, tended to get blown off in position. Vertical landing easy. Control activity relatively low during hover and landing.	Only minor objectionable feature was getting blown off position periodically when trying to maneuver and hover. Fine attitude characteristics, well damped, low response to turbulence, comfortable case.
117	3C4 $\tau_\theta = \tau_\phi =$ 0.1	B-FB	0.424 0.319	2	Selected to get the response needed to overcome damping. Wide range of control sensitivities seemed acceptable.	Air taxi no problem. Good response to the control inputs, low response to turbulence, and the high drag helped in stopping and starting precisely and in holding desired velocity.	No problem.	Good attitude characteristics helped overcome the high drag and also the high rate of change of wing tilt which is now available helped to control hovering position quite accurately.	Could hover quite accurately. Also, could land without difficulty.	No objectionable features. Favorable features were the good damping and high drag which helped in maneuvers and quick stops.
		B-MB	0.416 0.345	4	Selected to attenuate the gusts.	Air taxi not difficult to perform. Position motions were nicely damped due to large drag parameter, attitude was quite predictable. The effects of gusts were somewhat large but didn't offer any great difficulty.	Could set up a desired velocity and maneuver quite well, stop very precisely without any trouble. Attitude control well damped, very predictable.	Was able to remain over the spot without any difficulty. Had to use wing tilt angle a good deal because of high drag but not difficult to perform this task.	Hover is probably the most difficult task to perform. Could hold position fairly well but it required appreciable control activity. Good deal of control activity needed for vertical landing.	Objectionable feature was the somewhat high response to turbulence. Position was nicely damped, attitude dynamics were good.
118	3C4 $\tau_\theta = \tau_\phi =$ 0.3	A-FB	0.399 0.349	2.5	Set to get desired attitude response. Attitude dynamics well damped and easily controlled.	Air taxi fairly easy except that fairly large attitudes required to initiate motion, however can stop fairly precisely at desired point. Control deflections relatively small.	Relatively easy to perform except that large attitudes are required to initiate the motion.	Fairly easy except that concentration is required to offset the mean wind. Considerable thrust rotation is required to maintain hovering position in the presence of the mean wind.	Hover performance very good with very little pilot attention required.	Attitude control is good and there is no evidence of control lags in the system. Most objectionable feature is high drag. In particular the gust effects on position disturb the aircraft.
		B-FB	0.349 0.277	3	Selected to counteract the damping effects.	Air taxi no problem. Did notice some slight oscillation in roll and pitch in response to control inputs, but not large and were easily controlled. Able to perform maneuver quite accurately.	Could stop quite quickly and had no problem setting up and maintaining a constant rate during the quick stop. Large speed stability aided stopping rapidly and precisely.	Able to remain over the spot quite well. Increased rate on wing tilt helps this maneuver.	Could hover precisely with fairly limited control inputs. Vertical landing no problem. Used wing tilt to help with longitudinal position control.	Only objectionable feature was the slight oscillation in response to roll and pitch inputs, but not particularly bad. Lots of damping, low response to gusts, and the high drag helped maneuvering and didn't seem to degrade hover or the turn maneuver. Had to closely watch wing tilt angle in the turn.
		B-MB	0.421 0.329	5	Selected to control aircraft response to turbulence.	Response to control inputs would have been fairly predictable and probably acceptable, but the turbulence effects were too large. Could perform the task but really had to concentrate. Difficult, had to constantly be taking care of the effects of gusts and watching to make sure wasn't blown off. Difficult to hold the desired velocity.	Could perform the task but really had to watch for the effects of gusts.	Did this fairly well but had to do it slowly because of the effects of the gusts. Got into some fairly large and relatively oscillatory attitude changes. Used wing tilt control a good deal.	Mixed feelings about ability to hover. Sometimes seemed to be able to do it fairly well, other times not so well. Could land it alright. Lot of control activity in both hover and landing.	Primary objectionable feature was response to turbulence.
119	3C4 $\tau_\theta = \tau_\phi =$ 0.6	A-FB	0.467 0.322	4	Set for adequate attitude control.	Air taxi fairly easy except with high drag required relatively large attitudes to initiate motion. Could stop motion relatively easy and hold hover position with very small control deflections.	No problems except in getting the aircraft moving, but could stop very accurately at desired spot.	Required anticipation with thrust rotation control; attitude control required just a slight amount of attention. Did use wing tilt control to hold hovering position while making the turn.	Hover performance good, but did get blown around a little bit in position.	Attitude control was fairly good but it did require a little attention to prevent it from becoming oscillatory and from drifting off desired heading.
		B-FB	0.461 0.404	3	Selected primarily to get the response desired. Difficult time getting proper attitude response.	In general, could perform the task fairly well. Air taxi was no problem. Attitude seemed predictable, and the high drag helped.	No problem.	Could perform this fairly well. Didn't have to worry too much about attitude and the large rapid wing tilt rate helped in controlling position.	Could hover accurately, no problem. Vertical landing wasn't particularly difficult. Only thing annoying was the difficulty in getting the control response that was needed.	No real objectionable features, some slight oscillation in pitch and roll. The general good attitude characteristics are favorable features.
120	3C2 $\tau_\theta = \tau_\phi =$ 0.1	B-FB	0.409 0.260	4	Selected to control the speed-stability effects and the response to turbulence	Response to control inputs was predictable although it was slightly oscillatory and did notice some response to gusts. Able to initiate motion and to stabilize and hold desired velocities without any problems. Could stop precisely and hover accurately in the corners.	No problem here. Did notice a slight response to turbulence and some slight oscillation in pitch and roll.	No problem. Occasionally generated some fairly large and oscillatory roll and pitch actions, but was able to maintain position over the spot very well.	No difficulty with hover or landing.	The only objectionable feature seemed to be a slight oscillatory tendency in pitch and roll and some response to turbulence. Noticed the effects of speed stability when maneuvering, but these were easily correctable. Attitude response was fairly predictable and could perform all tasks without too much problem.

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{M_{\delta_e}}{L_{\delta_a}}$	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Turn-Over-a-Spot	Pilot Comments: Precision Hover, Vertical Landing, Secondary Dynamics	Pilot Comments: Overall Evaluation
1110	BC2 $\tau_\theta = \tau_\phi =$ 0.1	B-FB	0.390 0.298	5.5	Selected to control attitude because of poor damping and also to control attitude response to turbulence.	Performed air taxi fairly well but there were attitude oscillations. Attitude needs more damping for more precision control.	Was able to stop quickly but would prefer more attitude damping. Attitude response to turbulence quite large and difficult to hold velocities. Developed fairly large attitude angles when arresting motion.	Was able to remain over the spot fairly well due to a low drag. However, did develop some fairly large oscillations in attitude. Didn't use wing tilt control too much.	Able to hover quite precisely, held hover position without too much trouble. However, control activity was reasonably high during hover and landing tasks. Some interaction between dynamics but not too bad.	Would prefer to see more damping in pitch and roll, less response to turbulence, and more predictability in the response to control inputs. Configuration was controllable and could perform the task but not as easily as desired.
1111	BC4 $\tau_\theta = \tau_\phi =$ 0.3	A-FB	0.524 0.257	5	Set to control and stabilize pitch and roll attitude.	Air taxi maneuver requires some workload in that attitude is lightly damped and fairly gust sensitive. No problems initiating motion but small amount of anticipation required to stop at desired point. Gust disturbances on attitude seemed to be the biggest problem.	Can be performed readily however some anticipation is required to stop at desired poin .	Heaviest workload is in offsetting gust disturbances on attitude and maintaining attitude stability. Very little wing tilt was used in [illegible] position.	Hover performance was fairly good but attitude control required some attention.	Most objectionable features of this case were (1) the control lags in both pitch and roll and (2) the gust disturbances on pitch and roll. More damping would be desirable. Adequate performance requires considerable pilot concentration.
		B-FB	0.347 0.270	5	Selected to control oscillations in pitch and roll to get attitude response desired.	Problem here was oscillatory nature of roll and pitch, although never felt control would be lost. Was able to stop fairly precisely and to control velocities pretty well, but did have to pay a significant amount of attention to pitch and roll.	No great problem here, but attitude tended to wander around and had to pay attention to it.	Was able to remain over the spot quite well, but pitch and roll required attention. Oscillatory nature of pitch and roll was an annoyance.	Hover wasn't any great difficulty, could hold it pretty accurately but did get some moderately large attitudes because of their oscillatory nature. Could land quite well.	Didn't care for the oscillatory characteristics in pitch and roll and it seemed that speed stability and the gusts excited oscillations and then would have to damp them. Pitch and roll were still controllable and low drag helped during the hovering and the turn.
		B-MA	0.424 0.319	7	Selected to control the gusts and also the oscillatory attitude characteristics.	Very difficult. Was constantly see-sawing in both pitch and roll, trying to keep approximate desired velocity. Couldn't perform this task precisely or in any reasonable time.	Very difficult to stop at desired point and got into some large, oscillatory attitudes.	Again attitude was in constant oscillating motion. Could remain close to the square but really was forcing attitude back and forth. Did use wing tilt a little bit, wasn't really critical.	Couldn't really stay over hover point consistently. However, hover performance not too bad compared to other subtasks. Did manage to land it. Lot of control activity in both hover and landing. Definitely some interaction between roll and pitch.	Objectionable features were the oscillatory nature of attitude and response to turbulence. Really had to watch the oscillatory attitude characteristics which were difficult to damp.
1112	BC2 $\tau_\theta = \tau_\phi =$ 0.6	A-FB	0.387 0.393	8	Set in attempt to maintain attitude stability.	Air taxi very difficult because of difficulty in holding attitude precisely. No problem in initiating aircraft motion as drag seemed relatively low. Some difficulty holding precision hover at the end of maneuvers. Excessive attitude changes often took place due to inability to control attitude. Control deflections were quite large and at times developed PIO-type oscillations.	Maneuver somewhat difficult due to the very poor attitude control.	Required very little wing tilt compensation for mean wind. Most concentration was on maintaining attitude stability. Height control suffered somewhat because of the high workload in pitch and roll.	Hover somewhat difficult because couldn't control attitude accurately. Control activity was large.	Most objectionable feature was inability to control roll and pitch attitude due to the dynamics being oscillatory, lightly damped, and influenced by control lags. Task performance generally quite poor. Considerable compensation required just to maintain control at times.
		B-FB	0.414 0.374	8	Selected to control gusts and to some extent counteract effects of control lags.	Could just perform the maneuvering task. Was in constant oscillation in both pitch and roll. Any control input built up an oscillation which required considerable effort to damp. Difficult to stabilize and hold desired velocity and to stop precisely and hover. Some large attitude excursions occurred.	Same problems as with air taxi. Could stop the aircraft but large attitude excursions occurred.	Managed to retain hover position while turning but attitude went into wild oscillations and just about lost control. Developed one extended PIO in pitch. By stopping control inputs was able to gain control.	Could hover but not as precisely as desired. Attitude oscillations made it difficult. Did manage to land, but it was tough. Lateral dynamics definitely affected longitudinal dynamics and vice-versa.	The attitude characteristics in both roll and pitch are very objectionable. Roll and pitch in constant motion through large angles.
		B-MP	0.309 0.310	10						Uncontrollable. Tried lifting off and hovering. Couldn't remain stationary for more than 5 or 10 sec without developing a PIO. Seemed to start in pitch then would couple in some lateral motion. Tried six or seven different times, but just couldn't keep attitude under control.
1113	BC6 $\tau_\theta = \tau_\phi =$ 0.1	B-FB	0.432 0.345	4	Selected to give response needed in pitch and roll and also to counteract the effects of turbulence.	Could perform this maneuver fairly well although did have to constantly attenuate gust effects to hold preselected attitude angle. High drag helps the maneuvering task. Able to stabilize fairly well desired velocities.	No great problem. The high drag helps, again have to watch attitude response to turbulence, but attitude seems to be relatively predictable.	Performance fairly good. Don't see significant attitude oscillations.	Hover performed fairly well. Significant amount of attention required to attenuate gusts. Can land fairly well too.	Primary objection is the response to turbulence in pitch. Attitude seemed fairly predictable. Large drag helped in maneuvering and quick stops.

TABLE B-II (Continued)

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{M_{\delta_e}}{L_{\delta_a}}$	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
1114	335 $\tau_\theta = \tau_\phi = 0.3$	A-FB	0.316 0.235	4.5	Selected for adequate control of the oscillatory attitude dynamics.	Rather large attitude changes required to initiate motion but could stop with great deal of precision and could hover fairly well except for being blown around in position occasionally.	Greatest problem was initiating the motion. Could stop quite easily at desired point.	Got blown around quite a lot, had to use considerable wing tilt control with anticipation in attempt to maintain hovering position.	Hover workload wasn't too high although did get blown around in position. Control activity relatively low.	Most objectionable feature was that attitude dynamics seemed to need a little more damping. Some response to gusts. Rapid control inputs used during quick stop tended sometimes to develop PIO.
		A-FB	0.333 0.257	5	Selected primarily to get attitude under control and to control attitude in presence of oscillations (which weren't too difficult to control).	Response to control inputs somewhat oscillatory. Prefer more damping. Able to initiate motion and stabilize and hold desired velocities pretty well, although oscillatory characteristics did somewhat affect ability to hold velocities.	Generally could come to the stop fairly accurately and hold hover without too much difficulty. High drag apparently helped. Slows off a little when trying to come to a desired position.	Dynamics did tend to make it more difficult than if more damping had been available. Rapid wing tilt rate has improved things considerably.	Hover not particularly difficult, although had to control gust effects. Attitude slightly oscillatory.	Objectionable features - slightly oscillatory characteristics in roll and pitch. Favorable features - high drag helped during the maneuvering and quick stop.
		B-MB	0.398 0.388	7	Selected to control turbulence and also effects of speed stability during the maneuver.	Could perform the task, but very difficult and not very precisely. Very difficult to control attitude and periodically would develop minor PIO, especially in roll.	Difficult to smoothly transition desired quick stop position. Sometimes got into fairly large attitudes. Poor performance.	Difficult. Got way off in hover position a couple of times. Constantly rolling and pitching and wallowing back and forth. Never really stabilized attitude. Used considerable wing tilt control.	Wasn't able to hover particularly well. Periodically oscillated out of position. Landing wasn't very precise. A lot of control activity required. Significant amount of interaction.	Attitude control very objectionable. Large response to gusts. Large speed-stability effects when maneuvering and very oscillatory attitude characteristics. Very difficult to stabilize once an oscillation started. Had to be very careful about trying to stabilize attitude due to apparent lag effects.
1115	306 $\tau_\theta = \tau_\phi = 0.6$	B-FB	0.336 0.397	8	Selected to control large oscillations which result in pitch and roll.	Response to control inputs is very, very disagreeable. Large oscillations result that need a very great deal of compensation to be able to perform the task at all. Can't perform the task precisely or stabilize and hold velocities. Significant response to turbulence.	Can be performed. Large drag helps as it does in maneuvering, but still quite a difficult task to perform.	Very, very difficult to perform. Tend to develop large attitudes and at one point was in an extended PIO, just managed to regain control.	Never very difficult because of oscillatory dynamics. Just no way to stabilize the dynamics. Constant compensating inputs required. Very definitely the lack of damping in roll affected pitch and vice-versa.	Oscillatory characteristics very objectionable in pitch and roll along with inability to damp them. Sometimes had to grab hold of the stick and hang on as only way able to retain control. Almost lost control once.
1116	303 $\tau_\theta = \tau_\phi = 0.1$	B-FB	0.407 0.351	6	Selected primarily to control aircraft response to turbulence and to compensate for the lack of damping and effects of speed stability in maneuver and quick stop.	Response to control inputs was not particularly good. Large attitude oscillations resulted when attempting to maintain velocity. Missed desired stopping points several times due to the effects of the speed stability, turbulence, and gusts. Attitude control was a problem.	Could stop fairly quickly but attitude control was a problem.	Wasn't particularly difficult to remain over the spot because of the low drag. However, attitude control was a problem. While diverting attention to wing tilt indicator sometimes got into very large attitudes. Really more worrying.	Could hover quite well but it required a good deal of control activity. There was also a problem with interaction of pitch and roll dynamics.	Objectionable feature was lack of attitude damping. Had to be very conscious of the attitude response to turbulence and response to control inputs.
		B-MB	0.297 0.337	5	Selected to control attitude and turbulence.	Performed maneuver pretty well, but prefer to have more damping. Difficult to maintain the desired velocities, have to watch attitude fairly closely and attenuate the response to turbulence.	Could perform task fairly well. Could certainly stop quickly enough. Developed some attitude angles a little larger than desired but could perform the task fairly well	Remained over the spot quite well. Low drag helped. Didn't use wing tilt control too much.	Could hover quite precisely, no real problem there. Vertical landing not difficult. More control activity than desired for satisfactory case. Some interaction between pitch and roll dynamics.	The objectionable features were the low level of damping in attitude (really needed some more) and moderate response to turbulence. More pilot control activity required than is acceptable or satisfactory.
1117	303 $\tau_\theta = \tau_\phi = 0.3$	A-FB	0.456 0.455	9	Selected to maintain attitude control to prevent PIO situations.	During air taxi attitude control very difficult and occasionally got into PIO situations. Had to anticipate desired stopping point. Very difficult to come to precise hover. Excessive attitude changes caused by gusts. Control deflections rather high frequency and large amplitude.	Difficult because rapid attitude control induced PIO situations in both pitch and roll at times.	Most difficult part of turn was to maintain attitude control. Position control difficulty only because of poor attitude control.	Hover not too difficult and performance wasn't too bad, however attitude control required intense pilot concentration. Could land but had the attendant problems of very poor attitude control.	Most objectionable features were response to turbulence and unpredictable response to control inputs seemingly related to control lags and lightly damped dynamics.
		B-FB	0.441 0.365	7	Selected to control response to turbulence oscillations and effects of speed stability when maneuvering.	Could perform maneuver but required high concentration and constant concern with attitude. Definitely need more damping or less lags, probably both. Quite difficult to hold attitude.	Difficult. Could stop and in an imprecise way perform task, but just didn't have desired attitude control.	Tended to lose attitude when attention diverted. Difficult time controlling all the degrees of freedom. Also, lack of attitude control tended to cause large displacements in hover position.	Really couldn't hold hover position precisely, especially laterally. Vertical landing was difficult. Managed to perform task though. Certainly interaction between dynamics (roll on pitch and vice-versa).	Objectionable features - lack of damping, large speed stability, oscillatory characteristics in attitude and lag in attitude response.
		B-MB	0.423 0.375	[illegible]	Selected to control attitude oscillations and also attitude response to turbulence.	Difficult to perform maneuver precisely. Difficult to hold the desired attitudes in the presence of low damping and effects of turbulence. Couldn't maneuver smoothly and stop precisely	Also difficult because of difficulty in holding desired attitude.	Performed this maneuver fairly well, although there were large oscillations in roll and pitch. Drag was small so stayed over the spot pretty well. Little wing tilt control used.	Could hover fairly well, but a lot of control activity was required and developed large attitude oscillations. Managed to land alright but again a lot of work required. Didn't perform the task adequately.	Objectionable features - large attitude oscillations, lightly damped attitude characteristics, large attitude response to turbulence and some oscillations in attitude

TABLE B-II (Continued)

Case	Config. Parameters	[illegible]	[illegible]	PR	Pilot Comments: Selection of Control Sensitivities	Hovering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
1118	SD3 $\tau_e = \tau_a$ = 3.5	6.3	0.565 0.606	10	Selected in an attempt to stabilize pitch and roll attitude.	Air taxi maneuver very difficult because it was extremely difficult to stabilize attitude. When attention was diverted from display even momentarily frequently pitch and/or roll would be upset by a gust. Arresting these large attitudes difficult due to control lags and poorly damped dynamics. Very difficult to stay within ground track of the air taxi and control deflections were extremely large.	Very difficult to control due to poor pitch and roll control.	Main attention was devoted to stabilizing pitch and roll, for this reason control of both attitude and direction was very poor due to the high pilot workload. Used very little wing tilt control.	Hover difficult because of difficulty in stabilizing the inner loops.	Most objectionable feature was lightly damped attitude dynamics in combination with what seemed like fairly large control lags. Improvement is mandatory, it has major deficiencies. Never around feel certain that control would be lost.
		3.73	0.422 0.409	7	Selected to control oscillatory characteristics and response to turbulence.	Response to control inputs fairly good. Large oscillations and a significant response to turbulence make control somewhat difficult. Not able to stabilize velocities as well as desired. Ability to stop precisely affected somewhat. Low drag and oscillatory attitude characteristics make precision performance of task difficult.	One stop quickly out don't care for attitude characteristics.	Able to remain over a spot fairly well but can't divert attention from display for very long. Need more damping in pitch and roll.	Can't hover too well, the oscillatory attitude characteristics and response to turbulence tend to make it difficult to maintain hover position. Vertical landing is also difficult. Some interaction between pitch and roll and vice versa. The lack of damping in one tends to lead to upsets in the other.	The objectionable features are lack of damping and oscillatory characteristics in pitch and roll. At no time tended to lose control.
1119	NC2 $\zeta_e = \zeta_a$ = 0.30 $\omega_{n_\theta} = \omega_{n_\phi}$ = 3.33	3.73	0.295 0.270	7	Selected to control attitude but not so high as to excite oscillations.	Very difficult to perform with any precision. Attitude response to control inputs very, very difficult. Attitude (especially pitch) in almost constant motion. Tendency to develop PIO in lateral control. Only way could keep attitude under control was to periodically take hand off stick and let pitch damp itself. Couldn't perform air taxi well because of difficulty with attitude.	Difficult to perform because of poor attitude characteristics.	Managed to remain over spot fairly well but attitude difficult to control (in constant oscillation). Used a little wing tilt during turns in coordination with attitude changes.	Hover wasn't difficult, done best by holding stick essentially fixed. Whenever tried to change position developed oscillations that couldn't damp out with control inputs. Some interaction between pitch and roll dynamics.	Attitude characteristics very objectionable. Can't damp out oscillations except to hold stick fixed. Not much control over this case.
1120	NC_ $\zeta_e = \zeta_a$ = 0.22 $\omega_{n_\theta} = \omega_{n_\phi}$ = 3.33	3.72	0.300 0.272	10	Selected small control sensitivities in attempt to avoid exciting attitude. Can't make input without exciting attitude action.	Control must be almost hands off or very, very small inputs. Whenever maneuver attempted lose control. Built up large violent oscillations.				Can't control this because of inability to suppress attitude oscillations.
1121	SC1 $\zeta_e = \zeta_a$ = 1.0 $\omega_{n_\theta} = \omega_{n_\phi}$ = 3.33	2.72	0.353 0.314	4	Selected to get the response desired to overcome effects of the lags.	Could perform task fairly well. Noticed somewhat irritating oscillations in pitch and roll that had a tendency to sustain themselves, although low level and fairly quickly damped.	Could stop quickly and precisely, the lag was somewhat annoying when attempting to roll out after the quick stop.	Could perform task fairly well. Induced pitch and roll oscillations that were sustained for a while. Stayed over the spot fairly well, however.	Could hover quite precisely. Vertical landing was no problem.	Objectionable feature was small amplitude oscillations in pitch and roll which was somewhat irritating. Generally well damped, could control attitude fairly well.
1122	AC1 $\zeta_\theta = \zeta_\phi$ = .3 $\omega_{n_\theta} = \omega_{n_\phi}$ = 5.25	2.72	0.317 0.357	3	Selected to give response needed in attitude. No problems with lags.	Could perform task pretty precisely. Noticed the effects of gusts a little but it wasn't difficult. Could stabilize and hold velocities. Response to control inputs quite predictable. Nicely damped.	No problem stopping precisely and controlling attitude.	Could remain over the spot quite well. Task fairly easy to perform. Used wing tilt control during the turn.	Hover and landing no problem.	No real objectionable features. Maybe attitude was slightly responsive to turbulence. Noticed some small oscillations. Attitude control was good.
1123	SC? $\zeta_e = \zeta_a$ = 0.2	4.72	0.297 0.2??	2	Selected to get desired attitude response.	Response to control inputs quite predictable, well damped. Very steady and noticed very few oscillations. Could initiate and stabilize velocities, stop precisely.	Not difficult.	Could remain over a spot very well, attitude nicely damped, no problem with pitch and roll and no problem stopping on preselected headings. Used some small wing tilt. Wing tilt changes were not large.	Can hover very precisely. Vertical landing no problem.	Attitude control very, very good. Nicely damped, easy to control, very predictable and stable.
		8.92	0.307 0.355	2.5	Selected to get desired pitch and roll response.	Easy to perform. Easy to select desired velocity and hold it. Can stop precisely. No problems.	Performed the task quite precisely. Nice positive attitude response to control inputs. No noticeable lags.	Could perform quite precisely and remain over spot. Wing tilt control although not critical, was coordinated with with heading relative to the wind.	Hover and vertical landing no problem. No interaction among axes.	Favorable features included good, well-damped, positive pitch response and roll response.
1124	NC? $\tau_e = \tau_a$ = 0.3 $\zeta_e = \zeta_a$ = 0.1	3.93	0.357 0.354	3	Selected to get response desired to overcome the lags which were noticeable.	Task wasn't particularly difficult but did notice the effects of lags in response to control inputs. Had to be careful about making control inputs. Had to anticipate changes in attitude a little more than would have to without the lags. However, could perform task fairly well.	Sometimes overshot position a little bit. Some oscillations in position resulted because didn't get attitude reversed quickly enough.	Could do this fairly well, no real problems. Coordinated wing-tilt control with different parts of the turn relative to mean wind.	Hover and vertical landing no problem.	Found the lag in roll and pitch to be an objectionable feature, not really serious but it did result in performing the task less precisely than had previously.

TABLE B-II (Concluded)

Case	Config. Parameters	Pilot Sim. Mode	ω_{d_θ} / ω_{d_ϕ}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
1125	[illegible] $\zeta_\theta = 0.3$ $\zeta_\phi = 0$ $\zeta_\theta = 0.1$ $\zeta_\phi = 0.$	[illegible]	0.[illegible] 0.290	8	Selected in an attempt to gain control of pitch and roll oscillations.	Couldn't perform maneuver particularly well because of constant roll oscillations. Some oscillations in pitch, but roll was most annoying	Difficult to perform task with any precision because of constant roll oscillation. Really large angles (10 deg or more), constant oscillation and relatively high frequency	Came close to losing roll control during maneuver. Couldn't do it particularly well because of roll. Wing tilt control used a little.	Could stabilize aircraft in hover fairly well, but couldn't hover precisely. Could manage to land it but not with precision. Definitely some interaction between pitch and roll	Roll and pitch oscillations very objectionable, unacceptable.
1126	[illegible] $\zeta_\theta = \zeta_\phi =$ 0.2	[illegible]*	0.3[illegible] 0.33[illegible]	5	Selected to gain control of pitch response to turbulence and speed-stability affects the maneuvering.	Not too difficult to perform. Had to pay close attention to attitude. It was disturbed by turbulence, but fairly controllable. Could stabilize and hold the velocities and stop precisely at the corners fairly well.	Wasn't any real problem, could perform task fairly well but had to watch attitude as it was quite responsive to turbulence.	Could perform as to well again having to watch attitude, but remained over the spot fairly well. Only a little wing tilt control used as drag apparently small.	Held position without too much difficulty although was fairly active with control stick. Vertical landing no problem.	Objectionable features were the attitude response to turbulence and relatively low damping. However, attitude was reasonably predictable but required a good deal of attention and control activity.
		[illegible]	0.366 0.2[illegible]	5 [illegible]	Selected to gain control of attitude oscillations and attitude response to turbulence.	Could perform these maneuvers fairly well, but attitude responsive to turbulence. Some delay in the attitude response, needs damping. Had to watch attitude fairly closely to perform the maneuver well.	Had to be somewhat cautious in performing this task because didn't want to make too large an attitude change.	Performed this fairly well, but couldn't hold position quite as well as desired. Needed the wing tilt control to correct for mean wind effects	Performed hover quite well. Vertical landing not too difficult, managed to do it fairly well. Only a little interaction between dynamics.	Objectionable features are lack of adequate attitude damping and attitude response to turbulence. Attitude was controllable but required some effort.
1127	[illegible] $\zeta_\theta = \zeta_\phi =$ 0.3 $\zeta_\theta = \zeta_\phi =$ 0.1	[illegible]	0.3[illegible] 0.34[illegible]	[illegible]	Selected to gain control of oscillations in attitude.	Response to control inputs undesirable. Roll and pitch in almost constant oscillation of fairly large amplitude. Almost impossible to damp. Could stop fairly well, but difficult to maintain velocity	Lot of attitude motion, difficult or impossible to damp large amplitudes. Affected ability to stop at desired hover position	Again large oscillations, especially in pitch. Constantly overcontrolling it and occasionally would get a large oscillation in roll too. Very disagreeable. Had to concentrate so much on attitude that it took concentration away from hovering position.	Could hover fairly precisely, but fairly large, constant motion attitude excursions. Could land it alright. Some interaction between roll and pitch due to the oscillatory nature of the dynamics.	Found oscillations in pitch and roll very objectionable, very undesirable. No evidence of lack of control power.
		[illegible]	0.3[illegible] 0.317	7	Selected in an attempt to get attitude under control.	Very difficult to perform. Can't perform this maneuver precisely, difficult to control attitude, every now and then tend to build up attitude oscillations which are frightening.	Can't really perform a quick stop for fear of losing attitude control.	Did this very slowly and performed the task fairly well, but attitude was in constant oscillation. Needed wing tilt control to help perform the task.	Not too bad, but had to be careful not to make large inputs for fear of setting everything into oscillation again. Can perform the vertical landing. Definite interaction between roll and pitch dynamics.	Objectionable features include lack of damping, very oscillatory lightly damped response in pitch and roll. Very responsive to turbulence.

*[illegible] air data affect both control and SAS inputs

TABLE B-III

PILOT COMMENTS FROM THE STUDY OF PITCH, ROLL AND YAW CONTROL MOMENT LIMITS

Flying Qualities Results Given in Table A-IV

Case	Conf. Parameters	Pilot-Sim. Mode	K_{ω} / τ_a	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
141	RC1 $M_{c_m}=0.360$ $L_{c_m}=0.419$ $N_{c_m}=0.120$	B-7b	0.301 0.239	7	Selected to get attitude response desired.	Good response to control inputs in pitch and roll generally, however, when maneuvering forward tended to run out of control power occasionally and would pitch so that it was somewhat difficult to stabilize. However, in general could perform task fairly well.	Longitudinal quick stop developed a brief uncontrolled attitude excursion due to lack of control power but managed to recover fairly quickly.	Could remain over spot quite well, no difficulty. Well damped configuration.	No problem. Could hover precisely, sufficient control power. Vertical landing alright as well.	Only objectionable feature was lack of control power in pitch which showed up periodically during a maneuver and especially during the quick stop. In general configuration well damped.
		B-16	0.401 0.232	7	Selected to get the desired attitude response.	Generally could perform task fairly well. Didn't have any great difficulty in initiating velocity and stopping reasonably precisely. During the X maneuver was disturbed by a gust and couldn't control it due to lack of control power.	Generally no problem. Didn't notice any lack of control power but had previously during the X maneuver.	Could perform this fairly well but seemed that it lacked a little control power to control roll and pitch. Used the wing tilt controls a little.	Could hover fairly precisely without too much vertical. Vertical landing was no problem.	Objectionable feature was lack of control power, especially in pitch.
142	RC1 $M_{c_m}=0.396$ $L_{c_m}=0.457$ $N_{c_m}=0.132$	A-19	0.377 0.263	3	Set to achieve desired attitude response for maneuvering as there were very little gust effects noticeable.	Maneuvering performance was very good and required very little pilot concentration and very little compensation. Control deflections generally very small and low frequency.	Could perform quite well although a small amount of anticipation required to stop at desired point. Noticed very slight limitation of control power, but this occurred only on a very abrupt control input.	Quite easy, required very little pilot effort and very little thrust tilt trim control.	Hover performance was very good and very little pilot effort required.	Would still consider this a satisfactory configuration, with only mildly unpleasant deficiency being the lack of control power when performing quick stop maneuvers.
		B-79	0.356 0.243	2	Selected to get the attitude response required.	In general this wasn't a particularly difficult task to perform, however once or twice noticed a lack of control power. In two instances attitude pitched up and couldn't do anything to control it until the gust had passed. Limited in control power at an insufficient level.	Didn't have any problems.	Could perform this maneuver quite well remaining over spot very precisely. Used only small amount of wing tilt.	Could hover quite precisely. Vertical landing no problem. Moderate to low amount of control activity during hover and vertical landing.	Needs some more pitch control power. However, the configuration is nicely damped.
		B-16	0.317 0.256	3	Selected to get desired attitude response	No problem performing task. Could initiate and hold velocities and stop precisely. No excessive attitude changes involved.	Could perform this task precisely.	Could do this accurately and rapidly. Didn't have to use wing tilt control too much.	Seemed to have a little bit of trouble holding lateral hovering position but in general this task wasn't particularly difficult. Vertical landing not much of a problem.	Some slight difficulty hovering. Good attitude response, generally the task could be performed well.
143	RC1 $M_{c_m}=0.432$ $L_{c_m}=0.498$ $N_{c_m}=0.144$	A-72	0.780 0.700	2	Set to achieve desired attitude control for maneuvering.	Air taxi performance was very good with very little pilot compensation and effort required. Control deflections small and generally low in frequency.	Could perform quite well and there was no indication of a limitation on control power.	Performance was good with little pilot effort required. Very little thrust tilt trim control required to perform turn maneuver.	Hover performance very good with a minimum of pilot effort required.	Configuration had virtually no objectionable features.
		B-79	0.327 0.278	3	Selected to gain control of attitude and attitude response desired.	Could perform maneuver quite accurately, initiate all desired velocities with no problem. No obvious lack of control power. Seemed very easy to control.	No evident lack of control power anywhere. Could perform maneuver and stop precisely. Did not develop any large attitude angles due to lack of control.	No problem performing maneuver. Did it quite accurately, didn't have to rely on wing tilt control too much.	Could hover fairly precisely, but with a little difficulty. Vertical landing no problem. Moderate to small amount of control activity.	No real objectionable features, except for slight difficulty in hovering, otherwise it was a good configuration
144	RC2 $M_{c_m}=0.395$ $L_{c_m}=0.415$ $N_{c_m}=0.120$	B-71	0.337 0.259	3	Selected to get desired attitude response.	Not difficult at all to perform this maneuver. Could do it quite precisely, could initiate and stabilize velocities without any problems and stop precisely without large attitude angles.	Generally had no problems but when performing the roll quick stop once noticed a lack of control power.	No problems, performed this task precisely. Did use wing tilt control a little but wasn't really essential.	Could hover quite precisely without great deal of activity. Vertical landing no problem.	Objectionable feature is possible deficiency in roll control power which was a little annoying. Nicely damped configuration. Very responsive and predictable
		B-16	0.303 0.216	2.5	Selected to get response desired in attitude.	No problem. Very predictable response, could hold attitude quite well. Slight tendency to skate off past desired hovering point but that was fairly easily controlled.	No problem, again could perform these quite well, stop very abruptly and hold position after the stop without any problem	Could maneuver quite accurately and was fairly relaxed, no great difficulty. Wing tilt control used only a little during turn.	Could remain over hover point without any problem and didn't have to use too much control activity. Vertical landing not difficult either.	No real objectionable features. Little more drag desirable to help in maneuvering. Didn't notice any absence of control power during maneuvers.
145	RC5 $M_{c_m}=0.370$ $L_{c_m}=0.280$ $N_{c_m}=0.120$	B-16	0.390 0.268	7	Selected to get the response desired in pitch and roll and also in an attempt to overcome control power deficiency.	Would like to see a little more control power as it had some effect on ability to perform the task even when gusts were low. On one instance when maneuvering longitudinally got hit with a gust and just lost control of pitch for several seconds. This degraded task performance.	Went alright, didn't get combination of effects that caused loss of control, but would like to see more control power. Performance lacked precision.	Needs more control power. Did use wing tilt a good deal during this task.	Did hover alright. Managed to land vertically also.	Definitely needs more control power.
146	RC5 $M_{c_m}=0.380$ $L_{c_m}=0.360$ $N_{c_m}=0.150$	A-19	0.350 0.235	3		Response to control inputs during air taxi very predictable in both pitch and roll. Required somewhat large attitude changes to initiate motion during maneuvering but could stop very easily at desired point. Attitude changes not objectionable because of good attitude control. Workload low so could hold heading and altitude fairly well	Required large attitude changes. Only disagreeable feature was slight limitation on control power during quick stops but this was only mildly annoying and caused no degradation in performance.	Required somewhat large changes in wing tilt angle in order to hold hovering position but performance was relatively good because of good pitch and roll control.	Hover required very little control action. Most objectionable feature was gust disturbances in the longitudinal and lateral position of the aircraft.	Configuration is probably satisfactory without improvement. Mildly annoying lack or limitation of control power during the quick stop maneuvers.

TABLE B-III (Continued)

Case	Coef. Parameters	Pilot-Sim. Mode	$\frac{\delta_\theta}{\delta_\phi}$	PR	Pilot Comments					
					Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
LM6	BC5 $M_{c_m}=-0.380$ $L_{c_m}=-0.360$ $N_{c_m}=-0.150$	B-MB	0.297 0.218	2.5	Selected to get attitude response desired.	No great difficulty, did notice that when maneuvering laterally tended to get blown off in longitudinal position occasionally. Could correct for it fairly easily.	No difficulty. Could stop quite precisely and remain over spot. Added drag makes maneuvering and quick stopping somewhat easier.	Could perform this fairly accurately but had to watch carefully wing tilt position relative to heading. Used considerable wing tilt to perform task precisely.	Hover no problem, could perform fairly well. Vertical landing not difficult.	No real objectionable features, might be desirable to have somewhat lower drag, but could correct for most effects of drag. No real evidence of a lack of control power.
LM7	BC5 $M_{c_m}=-0.462$ $L_{c_m}=-0.440$ $N_{c_m}=-0.182$	A-FB	0.270 0.233	3	Set to gain adequate pitch and roll response during air taxi maneuver.	Air taxi relatively easy and performance good. Since attitude control was good had no problem holding heading or altitude. Control deflections relatively small and low frequency.	During rapid attitude changes seemed to notice a slight deficiency in control power. No effect on performance but it did momentarily seem to make roll and pitch slightly oscillatory.	Control easily maintained, no serious effect on task. Wing tilt use was very small.	Hovering, landing and takeoff done with little effort and relatively good precision.	Only mildly unpleasant deficiency was apparent saturation of pitch and roll control during very rapid large attitude changes during the quick stop maneuver.
LM8	BC4 $M_{c_m}=-0.820$ $L_{c_m}=-0.605$ $N_{c_m}=-0.175$	A-FB	0.260 0.194	6	Set to gain adequate roll and pitch attitude control for the maneuver task.	Good attitude control but did notice control power deficiencies during air taxi. Control deflections relatively low in amplitude and frequency.	Inadequate control power to do a good quick stop. Tended to use some wing tilt to assist in longitudinal quick stop maneuver.	Had some difficulty maintaining position during turn due to the mean wind effects.	Hover, landing and takeoff no difficulty.	Gust effects were minimal. The most objectionable feature was inadequate control power for rapid maneuvers and during turn maneuver. This prohibited rapid and precise maneuvering with the speed desired.
		B-FB	0.413 0.395	8	Selected in attempt to control pitch and roll attitude during gusts.	Difficult to hold maneuvering speed accurately. Pretty much at the whim of the gusts when they got too large. Had to wait till they receded and then attempt to continue. Couldn't perform task precisely.	Precision directly dependent on level of the gusts that happen to be present at any given time.	Lost control once. Began to develop a roll attitude when the gust hit, gave such a large roll attitude had to really make an effort to retain control.	Hover wasn't too bad but every now and then got socked with a gust and have to ride with it. Wing tilt control used fairly heavily to hold hovering position.	Control power inadequate when hit by a large gust. When the gusts were small configuration seemed to be relatively good but with large gusts difficult to retain control.
LM9	BC4 $M_{c_m}=-0.902$ $L_{c_m}=-0.665$ $N_{c_m}=-0.193$	A-FB	0.215 0.244	8	Set to achieve adequate attitude control in pitch and roll.	Not too much difficulty encountered in air taxi as long as speeds kept relatively low and small attitudes used. Attitude control required some concentration although gust disturbances were rather minor.	Presented some difficulty in that occasionally got hit by a gust while trying to maneuver rapidly and momentarily couldn't control attitude too well, although did not lose control.	Had to be done with rather gentle maneuvers and once had difficulty trimming out mean wind due to inadequate control power. Small amount of wing tilt required.	Hover was no problem, neither was landing or taking off. Control activity was rather low.	Most objectionable feature was limitation on control power in pitch; roll or yaw limitation did not seem to present any problem. Controllability occasionally in question. High pilot concentration required. Must be flown with small amplitude maneuvers.
		A-FB	0.432 0.404	4.5	Selected to control turbulence and effects of large speed stability.	In general could perform task fairly well. Every now and then hit with a large gust that disturbed attitude, but was always able to maintain control.	In general could perform them fairly well, but occasionally hit with a large gust that would prevent smooth performance of task.	Performance fairly good. Used wing tilt control a good deal.	No problem hovering, adequate control power. Apparently control power only inadequate when net ground speed, mean wind, and turbulence components were large.	Objectionable feature was deficiency in control power. In general configuration seemed to be fairly well damped. Response to turbulence wasn't that large, fairly low frequency.
LM10	BC4 $M_{c_m}=-0.984$ $L_{c_m}=-0.727$ $N_{c_m}=-0.211$	A-FB	0.304 0.261	4.5		Attitude control well damped and gust effects minimal. Maneuvering performance is good although relatively large attitude changes required to maneuver.	Noticed control power limitation when making rapid attitude changes although it does not seem to impair performance.	Relatively easy except that large amounts of wing tilt are required to effect mean wind effects.	Hover performance is relatively good and control power seems adequate.	Most objectionable features are the gust effects on aircraft position and the noticeable limitation of control power during rapid attitude changes.
		B-FB	0.431 0.404	3	Selected to control turbulence and speed stability when maneuvering.	Not difficult. Could maneuver precisely and hold attitude quite well and generally had no problem performing task. Noticed just once some minor deficiency in control power but maybe it was just a large gust.	Could stop precisely and hold desired velocities quite well. Didn't notice any lack of control power.	Performed this quite well. Didn't notice any lack of control power. Did use wing tilt a good deal during the turn.	Could hover precisely. Could also land quite well without any real difficulty.	No real objectionable features, some slight response to turbulence noted but not too bad. Dynamics are quite well damped and workload relatively low.
		B-MB	0.426 0.348	5	Selected to control effects of turbulence acting through speed stability mostly, also to control effects of speed stability while maneuvering.	Moderately difficult to perform. Had to attenuate effects of turbulence on pitch and roll. Affected ability to stop precisely to some extent, but could perform the task fairly well.	Didn't get into any maneuvering attitudes and performance relatively good.	Was difficult, couldn't hold hovering attitude particularly well and did develop some fairly large attitude changes. Lot of roll and pitching motion. Used wing tilt control a great deal.	Could hover precisely but it involved fairly large attitude changes and a lot of stick motion. Vertical landing alright. Some interaction between dynamics, at least during the turn.	The objectionable features were the large response to turbulence in pitch and roll and the lack of damping. Some lack of predictability in the pitch and roll response to stick inputs. Didn't notice any lack of control power, however.
LM11	BC4 $M_{c_m}=-1.066$ $L_{c_m}=-0.788$ $N_{c_m}=-0.229$	B-MB	0.426 0.334	4.5	Selected to get desired response and also to overcome effects of turbulence.	In general could perform this maneuver without any difficulty. Had to attenuate the effects of turbulence, however.	Could stop precisely and rapidly without excessive attitudes but had to watch the effects of turbulence.	Also could perform this maneuver fairly precisely but again turbulence was significant. Didn't notice any lack of control power in all these maneuvers, however did have to use wing tilt control a good deal in turn because of mean wind.	Required a fair amount of activity as did vertical landing. Had to attenuate the effects of turbulence.	Response to turbulence was somewhat too large. However, in general attitude was predictable in response to control inputs.

TABLE B-III (Continued)

Case	Conf. Parameters	Pilot-Sim. Note	M_{δ_e} / L_{δ_a}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
1302	[illegible] $M_{q_m}=0.890$ $L_{p_m}=0.750$ $N_{r_m}=0.170$	A-FB	0.267 0.331	7	Selected to control attitude response to turbulence and also attitude changes when maneuvering.	Didn't think I could perform this well. There were times when hit by turbulence and would almost come to a stop. Seemed to find attitude moving around quite a lot. Large attitude changes did result.	Generally could arrest velocity without too much difficulty. Kind of difficult to hold velocity. Also, on the X quick stop when trying to arrest speed got into a large attitude excursion and thought about to lose control.	Attitude control kind of shaky. Large attitude oscillations but could hold hovering position fairly well. No problem with directional control power. Wing tilt control used a good deal.	Could hover fairly accurately. As long as attitude changes were fairly small didn't get into too much trouble. Fair amount of control activity. Could land alright.	Objectionable features were the uncertainty in ability to control attitude. Got into one large attitude excursion and thought that control might be lost. Many times the attitude response seemed to be fairly well damped.
1303	[illegible] $M_{q_m}=0.979$ $L_{p_m}=0.825$ $N_{r_m}=0.167$	A-FB	0.215 0.138	10		Inadequate control power, difficult to establish velocities. At times saturated either pitch or roll control.	Inadequate control moment to develop velocities. Fore and aft motion could be controlled using wing tilt, but control moment inadequate to perform lateral maneuvers.	Lost control once and was unable to recover. Saturate control moment because of turbulence effects.		Inadequate roll and pitch control moments. Yaw control moments OK.
		B-FF	0.387 0.372	5	Selected to control attitude response to turbulence and the effects of speed stability while maneuvering.	Sometimes maneuvering velocities affected by turbulence through pitch and roll. But in general could maneuver fairly well but lacked desired precision. Once or twice introduced transient which may have been caused by lack of control power.	Could stop fairly quickly and didn't have too much trouble holding maneuvering velocities.	Didn't have too much trouble, but did go through some fairly significant attitude oscillations (particularly in roll). Had to use wing tilt a good deal.	Fair amount of control activity required to hover accurately. Could land without too much difficulty. Secondary dynamics had some interaction but nothing really severe.	Response to turbulence too large and noticed some lack of control power. Used maximum control input once or twice and wasn't able to attenuate gusts.
1304	[illegible] $M_{q_m}=1.366$ $L_{p_m}=0.600$ $N_{r_m}=0.204$	A-FB	0.226 0.127	8	Set for attitude response for air taxi.	Inadequate control power to maneuver very readily. Definite deficiency in both roll and pitch. Lateral maneuver was very slow because didn't have lateral thrust trim.	Not possible because initial velocities necessary for quick stops could not be developed.	Required concentration and the wind blew the aircraft quite a lot. Difficult to control because of inadequate control power. Had to make liberal use of wing tilt in an attempt to offset the deficiency in longitudinal control power.	Hovering and landing were no particular problem as control power was adequate for these maneuvers.	The most objectionable features were (1) deficiency in control power in pitch and roll when maneuvering and turning over a spot and (2) the gust effects on pitch attitude. It required some pilot attention. Must control carefully during maneuver to avoid losing control of the aircraft.
		B-FB	0.317 0.353	4.5	Selected to control attitude response to turbulence and effects of speed stability during maneuvering.	Generally response to control inputs was acceptable. Could stabilize velocities fairly well and stop without too much difficulty. Attitude kind of responsive to turbulence. Would like a little more damping.	Not too much difficulty. Noticed following abrupt stops there was no tendency to oscillate in pitch or roll. Adequate control power.	Could remain over the spot fairly well but did develop some large attitude changes. Desire more attitude damping. Control power was no factor. Wing tilt control used a good deal.	No real problem. Could hover quite precisely although fair amount of control activity required.	A fair amount of attitude response to turbulence and would like to see a little more attitude damping. Control power seemed adequate, noticed no large oscillations and no tendency to lose control.
		B-MR	0.393 0.325	6	Selected to control response to turbulence and speed stability when maneuvering.	Response to control inputs not quite as predictable as desired. Seems like acceleration-type response. Difficult to stabilize velocities and stop precisely. Gust disturbances are overwhelming, very large	Could stop fairly abruptly but it was difficult to do everything precisely. Didn't notice any lack of control power.	Managed to do this without too much difficulty, but did develop some fairly significant roll and pitch attitudes. Wing tilt control was used a good deal for mean wind effects.	Could hold position pretty well, but was always oscillating back and forth in doing so. Lot of turbulence to overcome when hovering. Vertical landing is moderately difficult. Probably some interaction effect between pitch and roll dynamics.	Objectionable features include large response to turbulence with the difficulty it caused in performing task precisely and also the low damping in roll and pitch. Didn't notice any lack of control power.
1305	[illegible] $M_{q_m}=1.157$ $L_{p_m}=0.975$ $N_{r_m}=0.221$	A-FB	0.256 0.259	7		Workload very high during the air taxi. Roll and pitch attitude fairly responsive to gusts. Attitude response to control inputs very lightly damped. Aircraft needs more SAS. Considerable gust disturbances in position and fairly large attitude changes required to maneuver. Limitation on control power evident, however, controllability of aircraft not in question.	Difficult to initiate the rapid maneuvers but could be stopped rather quickly. Limitation on control power evident and at times prevented the desired control of attitude.	Fairly difficult because of wind effects on the aircraft position, but control was adequate. Fair amount of wing tilt control required to hold position.	Hover performance fairly good, however pilot workload fairly high.	Most objectionable features were first the lightly damped, gust sensitive dynamics, and second, the limitation on control power. Considerable pilot compensation required, however, controllability not in question. The lack of control power and the insufficient stability augmentation a deficiency that must be improved.
1306	[illegible] $M_{q_m}=1.250$ $L_{p_m}=1.030$ $N_{r_m}=0.230$	B-MR	0.300 0.338	5	Selected to control attitude response to turbulence and attitude response to maneuvering velocities.	Could perform this task fairly well and initiate and stabilize velocities although it took some attention. Response to turbulence was fairly sharp, abrupt at times.	Could stop quite quickly and relatively precisely. Tended to introduce some fairly substantial and rapid attitude changes.	Performed this fairly well, including holding hover position. Used wing tilt control a good bit.	Fairly high workload when hovering but performance fairly good. Could land. Not too much interaction between dynamics.	Large attitude response to turbulence and the lack of predictability in the attitude response to stick inputs most objectionable features. Needs more damping.

TABLE B-III (Continued)

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{N_{\delta_r}}{I_{\delta_a}}$	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Lateral	Overall Evaluation
1017	BC2 X_{u_B}=-0.396 L_{v_B}=-0.457 X_{q_B}=-0.152 T_e=T_s=0.3 ζ_e=ζ_s=0.1	B-F3	0.339 0.264	4	Selected to get desired attitude response, seemed a bit sluggish in attitude.	No real problem. Did notice some slight lack of control power once though, seemed to get a little larger pitch attitude excursion than wanted, but in general could maneuver quite well.	Could perform task reasonably well. Had a little difficulty stopping where desired.	Not too difficult. No real hard requirements for wing tilt control.	Little disappointed with ability to hover. Would like to have a little more precision. Vertical landing no problem.	Objectionable features include some lack of control power and some apparent effects of lag in attitude control.
		B-MC	0.348 0.299	4.5	Selected to get desired response in pitch and roll; seemed to have to increase control sensitivity to overcome lag effects.	Performed quite well, no problems with initiating and holding desired velocity and didn't get into any particularly large attitudes.	Went fairly well except once during X quick stop seemed to exceed control power limits. Couldn't recover attitude as quickly as desired, although nothing serious.	Performed task fairly well. Little use of wing tilt control.	Couldn't hover quite as precisely as desired. Seemed to keep oscillating away from desired position. Could land alright.	Lag effect seemed to introduce some oscillations and overall performance was somewhat less precise than desired. Not particularly responsive to turbulence.
1018	BC1 M_{u_B}=-0.432 L_{v_B}=-0.498 X_{q_B}=-0.144 T_e=T_s=0.3 ζ_e=ζ_s=0.1	A-F3	0.233 0.294	4	Set for desired attitude response for air taxi. Slight overshoot and oscillation about desired attitude following rapid commands.	Air taxi performance relatively good. Slight lag in attitude control required only small increase in concentration to perform task. Control deflections remain small, however a little reverse high-frequency control required to stabilize desired attitude changes.	Performed fairly well, but some overshoot and oscillation about the desired commanded attitude.	Only small amounts of wing tilt control required. Maneuver was quite easy.	Hover performance very good and required very little pilot concentration. Control power seems to be quite adequate.	The most objectionable feature was the lag in attitude response and then the slight overshoot and oscillation about the commanded attitude change following rapid control inputs.
		B-F3	0.333 0.264	4	Selected to get the response desired in pitch and roll.	Not difficult. Could stop precisely. Could hold velocities without too much difficulty. Minor objection was that pitch and roll seemed to oscillate such that it was slightly difficult to stabilize.	Performance alright but had to damp out oscillations after completing maneuver.	Not difficult, could perform task fairly precisely, but tended to oscillate somewhat in pitch and roll.	Could hover adequately. Noticed some oscillation, some lack in response, a little bit of unpredictability in control response. Moderate amount of control activity required in hover and vertical landing.	Objectionable features were oscillatory nature of pitch and roll after significant attitude change. Would have to follow up to attenuate the overshoot. Configuration seemed fairly well damped, not responsive to turbulence.
		B-MB	0.398 0.245	3	Selected to get response desired in pitch and roll.	No problem, could perform task very nicely.	Also no problem. No lack of damping, the lags did not seem too annoying.	Could perform quite accurately. Didn't use wing tilt control too much.	Some difficulty here, but not too much, fair amount of control activity required but could hold hover position quite well.	No real objectionable features, some possible lag effects, nothing too bad. Nicely damped, easy to fly.
1019	BC2 X_{u_B}=-0.468 L_{v_B}=-0.540 X_{q_B}=-0.156 T_e=T_s=0.3 ζ_e=ζ_s=0.1	B-F3	0.346 0.275	2.5	Selected to get attitude response desired.	Response to control inputs acceptable. Seems to be some slight oscillation following control commands, however it was very small — very slight and of no major significance. Could stabilize and hold desired velocities, stop precisely and hover at the corners.	Able to stop precisely and hold position, no large attitude angles. Attitude was quite controllable, except for some slight oscillatory characteristics.	No difficulty, didn't have to rely on wing tilt control too much.	Could hover very precisely with a small amount of control activity. Vertical landing no problem.	No real objectionable features. Favorable features included low workload and nice stable response.
1020	BC1 λ_B=-0.369 L_{v_B}=-0.457 X_{q_B}=-0.132 T_e=T_s=0.6 ζ_e=ζ_s=0.1	B-F3	0.371 0.312	4.5	Selected to get desired attitude response.	Noticed some lack of damping and response to turbulence. Every now and then would overshoot attitude command and wouldn't compensate for lag characteristics too well. Could stabilize velocities fairly well, but had problems rolling in and out of maneuvers.	Got into some large attitude motions during X quick stop that weren't easy to damp, nothing dangerous but it was annoying.	Could perform maneuver fairly precisely and didn't use wing tilt control much.	Had a little difficulty in holding lateral hover position. Little more control activity involved and attitude not quite as predictable in hover as would like. Vertical landing no problem.	The oscillatory nature of pitch and roll and the apparent lack of control power or damping made attitude kind of unpredictable. Required a fair amount of compensation to control. It also affected the precision of task performance.
1021	BC1 M_{u_B}=-0.432 L_{v_B}=-0.498 X_{q_B}=-0.144 T_e=T_s=0.6 ζ_e=ζ_s=0.1	B-F3	0.336 0.305	4	Selected to get desired attitude response. Needed control sensitivity to damp out the oscillations that resulted from lags.	In general could maneuver fairly well. Irritating aspect was that attitude tended to oscillate after making a control input, had to make constant attempts to damp it out. This difficulty increased with abruptness of maneuver.	Induced attitude oscillations. Could perform task fairly well, some compensation required to damp attitude.	Performed task fairly well, but did get into some moderate oscillations in pitch and roll that affected task performance somewhat. Wing tilt control used a great deal.	Not too difficult to hover, small relaxed control inputs required. Vertical landing no difficulty.	Didn't care for the oscillatory characteristics in pitch and roll. It seemed to affect control capabilities somewhat. Liked low gust response; fairly relaxed case.
1022	BC2 X_{u_B}=-0.468 L_{v_B}=-0.540 X_{q_B}=-0.156 T_e=T_s=0.6 ζ_e=ζ_s=0.1	B-F3	0.346 0.277	3	Selected to get desired attitude response.	No difficulty, could perform task very smoothly and precisely. Noticed a little bit of oscillation in roll and pitch but nothing serious.	Could perform task quite precisely, didn't have any problems rolling and pitching in and out of the quick stops. A little bit of oscillation noticeable, but wasn't difficult to attenuate.	No difficulty, again noticed some oscillations in pitch and roll but they weren't particularly large and they weren't all that difficult to attenuate. Wing tilt control not used much.	Could hover precisely with little control activity. Could land without difficulty.	No real objectionable features except possibly the slight oscillation in roll and pitch that tended to develop in response to control commands, but it was low level. Nicely damped, low response to disturbances, easy to control
1023	BC3 M_{u_B}=-0.490 L_{v_B}=-0.400 X_{q_B}=-0.165 T_e=T_s=0.6 ζ_e=ζ_s=0.1	B-F3	0.368 0.312	4	Selected to try to overcome the lack of control power and damping in attitude	Did this fairly well. Air taxi no problem. Held velocities fairly well and could stop quite precisely.	Did the longitudinal quick stop alright. In lateral quick stop got into an oscillation which was kind of difficult to damp.	Didn't do this very well. Developed some large errors in position. Not sure if that was due to the attitude characteristics or due to not paying close attention to it. Did require the wing tilt a good deal.	Generally could do this fairly well. Did get pushed around once or twice, still not happy with the attitude response but it wasn't all that bad. Vertical landing OK. Reasonable amount of control activity in the hover and vertical landing.	Don't think there is quite enough control power in pitch and roll but in general could perform the task alright.

TABLE B-III (Concluded)

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{M_{\delta_e}}{L_{\delta_a}}$	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
1A24	RCS $M_{q_B}=-0.462$ $L_{p_B}=-0.440$ $N_{r_B}=-0.188$ $\tau_\theta=\tau_\phi=0.6$ $\zeta_\theta=\zeta_\phi=0.1$	4-FB	0.388 0.383	3.5	Selected to get response desired in attitude to overcome damping.	No problem maneuvering, attitude nicely damped and had sufficient control power to perform it well.	Comments as for maneuvering.	Somewhat difficult to remain over the spot but that was due to large drag rather than any attitude characteristics. Did perform the task reasonably well though. Wing tilt control was used a good deal, absolutely essential for this configuration. Monitored wing tilt angle a good deal.	Could perform this task fairly well. Noted a slight deficiency in control power which is acceptable. Would like to see a little bit more control power however. Vertical landing OK, moderate amount of control activity involved in hover.	Slightly objectionable feature was a slight deficiency in control power. Good deal of damping, nice response in attitude.
1A25	RCS $M_{q_B}=-0.304$ $L_{p_B}=-0.480$ $N_{r_B}=-0.199$ $\tau_\theta=\tau_\phi=0.6$ $\zeta_\theta=\zeta_\phi=0.1$	F-FB	0.433 0.339	4	Selected to overcome the damping and what may have been a lag in attitude response.	Response to control inputs was predictable, well damped. Could develop a smooth consistent velocity and stop precisely. No apparent lack of control power.	Could perform the task quite accurately. Perfectly acceptable behavior here.	Somewhat more difficult because of high drag, but good damping in attitude enabled performance of task fairly well. Did have to use wing tilt a good deal.	Only part of task that had some reservations about. Seemed to be a lag that prevented desired quick response in attitude needed to overcome gusts. Landing performance adequate. Fair amount of control activity involved.	Objectionable feature was apparent lack in attitude response when hovering which degraded performance slightly. Attitude appeared to be well damped.

TABLE B-IV

PILOT COMMENTS FROM THE STUDY OF INCREMENTAL PITCH CONTROL MOMENTS THROUGH STORED ENERGY

Flying Qualities Results Given in Table A-V

Case	Conf. Parameters	Pilot Sim. Mode	$\frac{M_{\delta_e}}{I_{\delta_e}}$	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
161	BC1 $M_{c_m} = 0.356$ $\Delta M_c = 30\%$ $\tau_\Delta = 0.05$	B-MB	0.274 0.198	5.5	Selected to get the attitude response needed to overcome the effects of damping. Wide range of control sensitivities apparently satisfactory.	No problem laterally, but when moving forward at times lost control of pitch attitude to some extent, it would just begin to rise without control. Also noticed lack of control power when pitching up to arrest forward velocities.	Couldn't really perform an accurate quick stop maneuver. Tended to pitch up and just hang there until attitude came back down again after velocity stopped.	No problem. Wing tilt control used a little to help in the turn.	Hover not difficult. Vertical landing no problem.	Objectionable feature was noticeable lack of control power during forward maneuvers and forward quick stops. Other than that it was a good configuration.
162	BC1 $M_{c_m} = 0.356$ $\Delta M_c = 30\%$ $\tau_\Delta = 0.10$	A-FB	0.320 0.251	3	Set for desired attitude response for maneuvering	Very small attitude changes required to sustain velocity. Had to anticipate somewhat the desired stopping position but in general the air task performance was good. Pilot workload low, no had no difficulty holding altitude and heading.	During maneuver noticed a slight deficiency in control power, pitch particularly, but at no time lost control of the aircraft nor did it require very much pilot attention to avoid getting into that kind of a situation.	Performance was very good. Workload was low and virtually no thrust tilt trim was required	Hovering and landing was excellent with very little control activity required	Overall the most objectional feature was the slight limitation of control power during the quick stop maneuver, but it had very little effect on task performance.
		B-FB	0.300 0.224	5	Selected to get the attitude response desired.	Good response to control inputs, no problem initiating and stabilizing velocities, possibly only once or twice noticed a small lack of control power when pitching up after moving ahead longitudinally, but these were relatively minor effects.	Performed these with no difficulty and noticed no lack of control power.	Easy to perform. Used wing tilt only slightly.	Not difficult, didn't notice any lack of control power here. Vertical landing not difficult.	Did notice a slight lack of control power once or twice but nothing serious. Well damped configuration.
163	BC1 $M_{c_m} = 0.356$ $\Delta M_c = 30\%$ $\tau_\Delta = 0.20$	C-FB	0.303 0.253	4.5	Selected to get the attitude response needed to overcome the damping.	Generally could perform task well. Once or twice noticed the nose was pushed up slightly by the gusts while maneuvering. Also, there tended to be some slight pitch-up tendency when arresting velocities, but in general could perform this task fairly well.	Didn't encounter any problems here but was careful when pitching up to stop the motion	Performed this task quite well with little difficulty. Didn't have to use wing tilt control a great deal.	Hover and vertical landing no problem. Could perform both accurately without much control activity	Were times when lack of control power noticed. Had to watch stick inputs somewhat in order to insure that large pitch attitudes weren't developed.
		B-MB	0.254 0.198	4	Selected to overcome attitude damping and get desired attitude response.	No problem performing task. Noticed some slight absence of control power when maneuvering forward and attempting to arrest maneuvering velocities, but generally could perform these maneuvers quite accurately.	Generally no problem, especially laterally. When trying longitudinal quick stops noticed slight deficiency in control power when attempting to arrest forward velocities abruptly.	No problem. Wing tilt control was used to a slight extent when turning over the spot.	Precision hover and vertical landing not difficult. No interaction among dynamics	One slight objectionable feature was the moderate deficiency in control power. Wasn't a real big problem, however.
164	BC1 $M_{c_m} = 0.356$ $\Delta M_c = 50\%$ $\tau_\Delta = 0.20$	B-MB	0.297 0.251	2	Selected to overcome ΔMG and get the attitude response wanted.	No difficulty, very pos. Stable attitude responsible to select and stabilize velocities with no difficulty and stop precisely	Can stop abruptly with no apparent lack of control moment. No large attitude motions.	Could perform quite well. Don't have to use too much wing tilt.	No problem. Can hover precisely with little control motion. Vertical landing also can be accomplished precisely. Secondary dynamics - No interaction	No objectionable features. Favorable features - predictable attitude response, low response to turbulence
165	BC3 $M_{c_m} = 0.300$ $\Delta M_c = 30\%$ $\tau_\Delta = 0.1$	B-FB	0.310 0.255	7	Selected to get desired attitude response.	Difficult to hold longitudinal velocity because of a lack of control power. Attitude seemed damped, but periodic gust disturbances annoying. Developed large pitch-up attitude when arresting velocity because of deficient control power.	Difficult to control position and velocity precisely.	At times couldn't position pitch attitude as desired because of the gusts. Had to use wing tilt a great deal, difficult to hold position.	Could generally hover position but blown off once or twice. Not too difficult. Secondary dynamics - No interaction	Objectionable features - Serious deficiencies in control power.
166	BC5 $M_{c_m} = 0.300$ $\Delta M_c = 30\%$ $\tau_\Delta = 0.05$	B-FB	0.314 0.256	6	Selected to overcome the ΔMG and get desired attitude response.	Could stabilize velocities fairly well, but noticed deficiencies in control power periodically. Had some difficulty controlling pitch attitude, tended to develop large pitch-up angles.	Could perform subtask fairly well, but had to be careful of pitch. Couldn't make inputs too abruptly	Could perform fairly well. Didn't have any problems with pitch control. Used wing tilt a good bit.	Noticed a lack of control moment. Attitude sluggish in responding	Noticeable deficiency in control moment.
167	BC1 $M_{c_m} = 0.300$ $\Delta M_c = 30\%$ $\tau_\Delta = 0.2$	A-FB	0.367 0.267	4.5	Set to achieve attitude control necessary for maneuvering	Performed fairly well. Relatively large attitude changes were required to overcome the drag of the aircraft. Occasionally got blown off ground track by gusts. Control moment quite adequate for maneuvering subtask.	Required large attitude changes. Noticed control moment deficiency a few times, momentarily couldn't hold or arrest attitude motion.	Required some effort and considerable wing tilt to offset the mean wind effects. Control moment was quite adequate.	Performance was quite good, only a low level of pilot effort required.	Attitude dynamics were basically good. Only problem was that control was periodically deficient.
		B-FB	0.398 0.258	4	Selected to overcome damping and to get desired attitude response	No difficulty. Could hold desired velocities and stop precisely. Once or twice attitude got blown off and needed the control moment to recover rapidly, not a major problem	Performed this task precisely, held attitudes and velocities without difficulty	Performed quite well without too much control activity or too great a workload. Used wing tilt a good bit, however.	Precision hover and vertical landing could be accomplished precisely with moderate control activity.	Lack of control power when maneuvering. Annoying, but not a major deficiency. In general, the configuration was well damped.

TABLE B-IV (Concluded)

Case	Conf. Parameters	Pilot-Sim Mode	M_{δ_e} / δ_a	PR	Pilot Comments					
					Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
15[illegible]	80% M_{c_p} = 0.900 ΔM_c = 0 τ_A = 0	B-MA	0.371 0.333	5.5	Selected to control attitude response to turbulence.	Could perform fairly precisely. Turbulence effects strong, once or twice noticed deficiency in pitch control moment.	Could perform fairly well. Noticed slight deficiency in control power when arresting forward velocities.	Difficult to perform. Had to use wing tilt a good bit. Pitch, roll attitude oscillations fairly large.	Not difficult. Vertical landing OK. No major interaction.	Response to turbulence and slight deficiency in control power annoying. Predictable attitude response.
1509	80% M_{c_p} = 0.900 ΔM_c = 30% τ_A = 0.05	B-Ma	0.381 0.342	5	Selected to get desired attitude response and enable to overcome turbulence response.	Could perform fairly well. Noticed slight lack of control power when maneuvering forward.	Could perform fairly well but slight deficiency in control power.	Moderately difficult to perform. Had to watch effects of mean wind. Like more damping. Used wing tilt control a good bit.	Periodically got blown off desired hovering position. Vertical landing no problem. No interaction.	Response to turbulence objectionable, slight deficiency in control power.
1510	80% M_{c_p} = 0.900 ΔM_c = 30% τ_A = 0.1	A-F8	0.375 0.310	6	Set to achieve desired attitude changes for maneuvering.	Difficult to maintain large attitudes required to sustain velocity. Noticed no control power deficiencies. Could stop fairly precisely at desired point. Required pilot concentration, and heading and altitude control suffered.	Difficult because of large attitude changes required to start and stop motion. Control power inadequate to maintain desired attitude during forward motion.	Adequate control power; considerable concentration required because of position disturbances. Considerable wing tilt required.	Performance quite good, gust position disturbances annoying.	Momentary inadequacies in control power during quick stop objectionable.
		B-F3	0.401 0.333	5	Selected to overcome damping and attitude response to turbulence.	Performed without too much difficulty. Noticed slight deficiency in control power.	Could stop fairly precisely and didn't notice any deficiencies in control power.	Moderately difficult due to large drag parameter. Used wing tilt a good deal and had to monitor tilt angle meter closely.	Moderately difficult; developed some fairly large attitudes attempting to hold hover. Could land with no problem, fair amount of control activity. No interaction.	Significant response to turbulence and some deficiency in control power.
1511	80% M_{c_p} = 0.900 ΔM_c = 30% τ_A = 0.2	A-F8	0.291 0.241	7	Set for maneuvering.	Maneuvering fore and aft difficult because of lack of pitch control moment. Could control ground track fairly well but performance very slow because of lack of attitude control.	Difficult to develop desired speeds. Felt inadequate pitch control moment during rapid attitude changes.	Considerable wing tilt to offset mean wind effects.	Hover performance fairly good, control moment seemed adequate. Biggest problem were gusts acting on drag parameters.	Dynamics fairly good. Bothered by lack of pitch control moment, particularly during quick stop.
		B-F4	0.301 0.20[illegible]	8	Selected to control turbulence.	No problem performing. Had to counteract effects of turbulence, however. Could stabilize velocities and stop precisely. No noticeable lack of control moment.	Not too difficult. Turbulence affected precision slightly.	Somewhat difficult because of large drag parameters. Performed task fairly well; however, had to use wing tilt a good deal.	Precise hover required appreciable control activity and concentration. Vertical landing not too difficult.	Response to turbulence noticeable but attitude fairly well damped.
		B-M3	0.392 0.337	4	Selected to get desired attitude response to control turbulence effects.	Could perform quite well and didn't notice any lack of control moment. Pitch and roll somewhat responsive to turbulence, but very predictable.	Could perform without any real difficulty. Even when maneuvering forward and pitching to abruptly noticed no lack of control moment.	No question of controllability, but had to turn slowly to remain over spot. Used wing tilt control carefully and coordinated it closely with direction of mean wind.	Could perform hover quite well; vertical landing no problem. No interaction.	Only objectionable feature is attitude response to turbulence, but not bad once.
1512	80% M_{c_p} = 0.979 ΔM_c = 30% τ_A = 0.1	A-F3	0.246 0.128	9	Lack of control moment made setting sensitivity meaningless. Used stick as on-off controller.	Very difficult, performance poor because of inadequate control moment. Never lost control of aircraft, however.	Couldn't perform because control moment inadequate.	Difficult; large wing-tilt requirements.	Hover performance quite difficult because of inadequate control moment and effects on aircraft position.	Serious deficiency in pitch control moment.
		B-F3	0.389 0.340	6	Selected to get control over attitude response to turbulence and speed stability effects.	Difficult because had to concentrate on attitude and constantly attenuate turbulence effects.	Had to attenuate attitude turbulence response but could hold velocities relatively well and stop abruptly.	Somewhat difficult. Pitch and roll drifted off during turn because of inadequate damping. Used wing-tilt control a good deal.	Hover difficult, but could be performed well with considerable stick activity. Vertical landing could be accomplished but required attention. Some interaction between longitudinal and lateral dynamics.	Large attitude response to turbulence objectionable. Noticed lack of control power once or twice.
1513	80% M_{c_p} = 0.979 ΔM_c = 10% τ_A = 0.2	A-F3	0.254 0.1[illegible]	5	Set to control attitude sensibilities.	Quite difficult because of gust sensitive and lightly damped attitude dynamics. Pilot workload quite high. Lack of control moment evident in pitch. Heading and altitude control impaired.	Difficult in longitudinal direction. Noticed control moment limitations in pitch.		Hover performance adequate but required appreciable pilot effort.	Poor attitude characteristics - high gust sensitivity and limitations on control moment.
		B-F2	0.410 0.299	5	Selected to control attitude response to turbulence	Could initiate and hold velocities fairly well but constantly attenuated effects of turbulence.	Could stop quite quickly. Had to be careful of turbulence effects.	Could perform quite well. Has tendency for pitch and roll attitude to drift off. Wing-tilt control used a great deal.	Could hover reasonably well but fair amount of control activity required. Vertical landing could be accomplished accurately.	Needs attitude damping or reduced response to turbulence.

TABLE B-V

PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL AND LATERAL INTER-AXIS MOTION COUPLING

Flying Qualities Results Given in Table A-VI

Case	Test Parameters	Pilot-Sim. Mode	δ_a / δ_e	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
101	BC1 $M_q = -2$ $L_p = -2$	A-FB	0.325 0.342	–	Set for getting desired response for air taxi maneuver	Performance during air taxi was good with a minimum of pilot effort. Control deflections were rather small and low frequency	Noticed coupling between pitch and roll when high angular rates were developed. This was somewhat annoying and required control correction	Performance was good and required very little thrust trim	Hover performance was very good with very little control effort required. Control activity was low	Overall quite good except when making rapid attitude changes was annoyed by cross coupling between pitch and roll axes. Seemed related to the angular rate of the aircraft and to the control input
		A-FB	0.359 0.295	3	Selected to get desired attitude rates	Not difficult. Attitude response relaxed, smooth. Reasonably predictable, some coupling evident but no large attitude changes in either pitch or roll resulted	Generally could perform fairly well, however did a time that when trying to arrest velocities needed to introduce some errors due to attitude coupling	No difficulty. Did use the wing tilt control a fair amount although it wasn't too necessary	Precision hover and vertical landing not difficult. The roll and pitch interaction did affect control somewhat in the quick stops	Only objectionable feature is roll and pitch interaction in quick stops. However, that's not a significant problem
		B-MB	0.349 0.291	3.5	Selected as a compromise between avoiding excitation of attitude disturbances through coupling and being able to control adequately	No real difficulty. Coupling effect was there as kind of a low frequency perturbation or control inputs, but generally, it didn't affect ability to control	Could perform these precisely. Never got into any trouble and could perform them about as precisely as desired. Coupling evident but it didn't seem to take that much effort to control it	No problem. Did use the wing-tilt control to small extent	Precision hover and vertical landing no problem. Attitude interact us through the coupling. The coupling was evident, but didn't require too much effort to control	Coupling was evident and required some effort to control. Made somewhat smaller control inputs to damp down the effects of coupling, but could still perform task relatively well
102	BC1 $M_q =$ $L_p = 4$	A-FB	0.305 0.356	6.5	Set to get desired control response for maintaining aircraft attitude	During air taxi was annoyed by coupling between pitch and roll axes. This degraded ability to maintain ground track and to stop with precision. Also, because of increased attention required, height control and directional control was degraded	Pitch and roll coupling was really aggravated. Control of heading was degraded because of this	Wasn't too difficult and only small amount of thrust rotation was required	Precision hover performance was fairly good but had to use care to use low frequency, small control inputs	Most objectionable feature was the coupling between the pitch and roll axes. Workload was fairly high and had to use relatively small control inputs
		B-FB	0.376 0.293	5	Selected to get the attitude response desired and also to not excite the coupling	Could perform task relatively well but pitch and roll is almost constant notice. Fair amount of effort to keep desired attitude, to hold velocity and to stop precisely	Longitudinal quick stop wasn't too difficult although tended to put in somewhat lower rates to avoid exciting the coupling. Lateral quick stop somewhat more difficult because of coupling with pitch attitude	Didn't perform this as precisely as desired due to attitude control difficulty. Did use the wing tilt control	Precision hover and vertical landing not too difficult. Definitely coupling is evident	The coupling is objectionable and requires some effort to attenuate it and control adequately
103	BC1 $M_{\delta_a}/M_{\delta_e} = 0.25$ $L_{\delta_e}/L_{\delta_a} = 0.25$	B-FB	0.362 0.290	3	Selected to get desired attitude response	Noticed some small oscillations in both pitch and roll due to apparent control coupling, but this was low level and no difficulty. Could perform task precisely without excessive attitude changes	Could be performed precisely. Coupling didn't detract from ability to perform task	Not difficult. Could keep attitude and control quite well	Precision hover and vertical landing not difficult. Some interaction between pitch and roll motion here, but at a low level and not difficult to control	Only mildly objectionable feature is the coupling
104	BC1 $M_{\delta_a}/L_{\delta_a} = 0.5$ $L_{\delta_e}/M_{\delta_e} = 0.5$	A-FB	0.362 0.308	2.5	Set to achieve desired response for maneuvering	Air taxi performance was good. Could hold ground track and stop at desired point quite easily. Control deflections rather small and low frequency. Control about all axes was good	Presented no particular problems	Very little trim required for turn over a spot	Precision hover performance very good with minimal pilot effort required. The dynamics and control inputs of one axis did not affect another axis	Overall the configuration was very good and had good control response and low gust sensitivity
		B-FB	0.322 0.293	3.5	Selected to get desired attitude rates	Attitude control seems fairly low frequency and relaxed, no oscillations. Some rolling evident but not a real problem. Can maneuver and stop precisely	Can perform the quick stop precisely. Some small pitch and roll oscillations but they are low frequency, low amplitude	Performed this quite accurately. Used wing tilt control to some extent	Precision hover and vertical landing no problem. Secondary dynamics - questionably some interaction between dynamics, but low level, not difficult	Some minor objection to the coupling but this is not a big problem
		B-MB	0.364 0.42	2.5	Selected to get the attitude response desired. Coupling didn't have any effect on control sensitivity	Could perform this precisely in both X and Y directions. No problem holding velocities. No large attitudes developed	Can stop quickly and precisely both in X and Y. Notice the slight coupling but it really doesn't affect control inputs	Not difficult. Can turn ... spot. Wing tilt control was used a small extent	Precision hover and vertical landing no problem. Secondary dynamics - coupling is evident, but not a big problem	No real objectionable features. Coupling is noticeable, but doesn't present any great difficulties. Nicely damped configuration, easy to control
105	BC1 $M_q = -2$ $L_p =$ $M_{\delta_a}/M_{\delta_e} =$ $L_{\delta_e}/L_{\delta_a} =$	A-FB	0.32 0.29	4	Set for maneuvering response of the aircraft	Had good control characteristics during air taxi. Could hold ground track quite well and stop at desired point. Control motions were relatively low amplitude and low frequency	Annoyed a little bit by coupling between pitch and roll during fairly large control inputs and high angular rates	Performance was good, little control effort required and very little thrust trim required	Precision hover performance good and little control activity required	Most objectionable feature was the control coupling during rapid attitude changes and rapid control inputs. With smooth control inputs and relatively low angular rates, control coupling hardly noticeable

TABLE B-V (Concluded)

Case	Conf. Parameters	Pilot-Sim. Mode	δ_e/δ_a	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Turn-Over-a-Spot	Pilot Comments: Precision Hover, Vertical Landing, Secondary Dynamics	Pilot Comments: Overall Evaluation
LC5	BC1 $M_q = -2$ $L_p = -2$ $M_{\delta_a}/L_{\delta_a} = 0.25$ $L_{\delta_e}/M_{\delta_e} = -0.25$	B-FB	0.316 0.264	4.5	Selected to get desired attitude response	Attitude response fairly relaxed, but appreciable amount of coupling present. Especially noticed pitch inputs when rolling and vice versa; disturbing and required some attention. Could perform the task adequately, but attitude control required some attention	Performed fairly well, although not too precisely. Coupling introduced attitude motions that were annoying.	Didn't do this very well for some reason. Not too difficult but should have been able to perform more precisely	Precision hover and landing no problem. Pitch characteristics affected control of roll and vice versa	Coupling was significant enough to disturb aircraft and require more attention to attitude control than would like
		R-MB	0.310 0.360	4	Selected to get the response desired and to help control the effects of coupling	Generally not too difficult. Could maneuver longitudinally and laterally with precision, but very definitely some coupling effects that needed corrective inputs	Coupling quite evident, especially when making rapid attitude changes	Not difficult. Could perform it rapidly and precisely. Used the wing tilt control to a limited extent.	Precision hover and vertical landing not difficult. Coupling definitely affected control, although it didn't appear to cause a deterioration in performance.	The coupling between roll and pitch was objectionable, looked like rate coupling. This was annoying, but it didn't lead to a loss of precision
LC6	BC1 $M_q = -4$ $L_p = -4$ $M_{\delta_a}/L_{\delta_a} = 0.5$ $L_{\delta_e}/M_{\delta_e} = -0.5$	E-FB	0.312 0.358	7.5	Selected as a compromise between that needed to control attitude motions and that which didn't excite pitch and roll response	Difficult to perform. Lot of somewhat unpredictable attitude motion both in pitch and roll. Apparently a lot of it is due to pitch and roll rates. Got into some fairly large attitudes. Can't perform this with much precision	Also difficult to perform. Annoyed by coupling. Can't perform this task precisely	Got into some large attitude motions, a lot of which seems almost unpredictable. Tend to change attitude very abruptly. Difficult to stabilize attitude	Precision hover and vertical landing not too difficult, but lacks precision. Seems to be a lot of interaction between pitch and roll which is quite disturbing	Objectionable features are the large amount of coupling and the rapid, fairly unpredictable response that it brings about in pitch and roll
LC7	BC2 $M_q = -2$ $L_p = -2$ $M_{\delta_a}/L_{\delta_a} = -0.25$ $L_{\delta_e}/M_{\delta_e} = -0.25$	B-FB	0.342 0.373	6.5	Selected to help get control of attitude oscillations	Difficult to perform precisely. Pitch and roll in constant oscillation. Significant amount of compensation required to maintain ground velocities and to stop accurately. Some relatively unpredictable motion in pitch and roll due to coupling.	Difficult to perform precisely, must be very careful about control inputs. Have to watch attitude closely when arresting quick stops. Got into fairly large attitude oscillations	Remained over the spot fairly well, but went into large pitch and roll oscillations while doing so. Wing tilt control used to limited extent	Can perform hover, but the attitude excursions are significant. Fair amount of interaction or coupling due to the light damping	Objectionable features: coupling response to turbulence and lack of damping. Difficult case to control
LC8	BC2 $M_q = -2$ $L_p = -2$ $M_{\delta_a}/L_{\delta_a} = -0.25$ $L_{\delta_e}/M_{\delta_e} = 0.25$	B-FB	0.442 0.399	6.5	Selected to get control of the pitch and roll oscillations	Fairly difficult task. Lot of attention must be paid to attitude control. Difficult to stabilize velocities and stop precisely, but can be done adequately.	Can perform task, stop precisely, but tend to introduce a lot of pitch motion and roll motion. Have to worry about suppressing those oscillations	Difficult to perform because can't look away from attitude and check the heading indicator without introducing fairly significant attitude errors. Use the wing tilt to moderate extent.	Precision hover and landing not too difficult, but both required attention	Objectionable features: response to turbulence, coupling, lack of damping. Difficult case

BLE B-VI

PILOT COMME : THE STUDY OF LONGITUDINAL
INDEI THRUST-VECTOR CONTROL

Flying Qualities Results Given in Table A-VII

Case	Conf. Parameters	Pilot, Sim. Run	[illegible]	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Turn-around	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
111	NCI 7.4 deg/sec	A-FB	0.389 0.775	2.5	NOT SELECTED	Good control and low pilot compensation. Longitudinal air taxi maneuver fairly easy with wing tilt control although it required some anticipation to stop at desired point. Relatively easy thrust rotation required to maneuver longitudinally.	Relatively easy but required anticipation to stop at desired point.	Performance very good and required very little effort. Wing tilt control used sparingly.	Precision hover performance quite good with very little effort required. Had very slight tendency to get into longitudinal position oscillation while controlling position with wing thrust tilt.	Overall, the good configuration, required very little effort.
		B-FB	0.314 0.242	4		Could perform this task relatively well. Bothered by slow rate of rotation of thrust vector angle, but if maneuvering rates kept small didn't have too much difficulty.	Got into a little trouble here because of slow rate of thrust rotation. Just couldn't get around as quickly as desired and overshot desired stopping spot.	Performed task relatively well and messed up a little on control toward end of maneuver and lost hovering position, but generally stayed over spot relatively well	Not difficult, nor was vertical landing	Objectionable feature primarily slow rate of change in thrust vector angle.
		B-MP	0.314 0.242	4.5		Maneuvering not difficult with independent thrust angle control. Could establish velocities and stop relatively precisely. Occasionally thrust rotation rate was inadequate but in general didn't affect ability to maneuver.	Rather difficult due to slow rate of change of thrust vector angle. Had to lead longitudinal motion a great deal with thrust vector angle control to stop where desired. At times resulted in long period of oscillating back and forth in position.	Task wasn't difficult with this mean wing tilt control. Very small amplitude motions throughout these tasks.	Precision hover not difficult. Rate of thrust rotation was sufficient.	Objectional feature - slow rate of change available in thrust vector angle
112	NCI 7-10 deg/sec	B-FB	0.314 0.242	4	NOT SELECTED	Could maneuver fairly well with precision. Had to be somewhat careful about building up rates which were too large because of inadequate rotation rate of thrust. Possibly would like a somewhat larger rate.	More difficult to perform in air taxi. Managed to stop precisely but in jockeying thrust vector back and forth got off in position a moment.	Relatively easy using thrust vector angle	Could hover quite well using only thrust vector angle. Vertical landing wasn't difficult.	Objectionable features - Would like to see a little higher thrust rotation rate. In arresting velocities had to lead corrections good but because of low rotation rate. Favorable features - Attitude stick damped
113	NCI 7-20 deg/sec	A-FB	0.389 0.276	3.5	NOT SELECTED	Could maneuver quite precisely and accurately using just thrust switch. Able to develop velocity control and stop precisely and hover at new position. Very little attention had to be paid to attitude control.	Could taxi and stop quickly and precisely and hold new position quite easily.	Think this was somewhat easier to perform than when controlling position with attitude changes. High thrust rotation rate helps a lot.	Also not difficult. Could hold position at all times using fairly relaxed thrust vector angle inputs. Vertical landing also not difficult.	No real objectionable features. The slight drawback was thrust rotation rate may have been somewhat large. It was difficult to command a small change in thrust angle.
		B-MP	0.314 0.242	3		Could maneuver forward and aft without difficulty. Like increased thrust rotation rate, but it's to the point where it's almost too quick. Can stop precisely and hold hovering position quite well. Don't introduce attitude changes when thrust rotated but can feel longitudinal accelerations.	No difficulty. Don't have to lead inputs by operating on leading or position rates as much as with lower rotation rates. Can wait until almost last moment until at desired position and then rotate thrust angle.	Not difficult to perform.	Precision hover and landing not difficult.	Slightly objectionable feature is the thrust rotation rate is somewhat too high. Affects precision with which thrust vector angle can be commanded, but in general is good configuration.
114	NCR 7-5 deg/sec	A-FB	0.329 0.286	4.5	NOT SELECTED	Could perform maneuver relatively well, although had to watch effects of gusts acting on position. Tended to get blown off in position a fair amount but could generally hold it without too much error. Would like little higher thrust rotation rate. Somewhat difficult to correct for small errors with this slow rate	Performed maneuver relatively well. Would prefer somewhat larger thrust rotation rate.	Not too difficult to perform. Think it's somewhat easier than if no independent thrust vector control.	Not difficult, could remain within the square relatively well. Prefer higher thrust rotation rate	Slow rate change of thrust vector angle was objectionable. Also high drag made it difficult to control, although task performance not too bad.
		B-MB	0.329 0.286	5.5		Could perform maneuver relatively well and hold velocities without much trouble. Didn't get into any trouble but didn't have much reserve capability. Would like little larger thrust rotation rate.	Couldn't perform task particularly well. High drag requires large changes in thrust vector angle to change velocity. Tended to overshoot desired stopping point because of low rotation rate, then oscillate back and forth in position.	Couldn't perform task as precisely because of high drag and wind effects.	Precision hover not too bad, but would like a larger thrust rotation rate. Vertical landing not too difficult.	Objectionable features - High drag makes control somewhat difficult in combination with low thrust rotation rate. One advantage of lower thrust rotation rate is that little pitching moment is introduced when thrust rotated.
115	PR 7-5 deg/sec	B-FB	0.329 0.286	4.5	NOT SELECTED	Could maneuver longitudinally quite precisely, stop fairly accurately, and hold hover without too much difficulty. Had to pretty much on thrust vector angle to control position.	Could stop quite precisely and rapidly with thrust angle control, although some difficulty holding position after stopping. Used thrust vector control almost exclusively.	Able to perform more accurately using thrust vector angle than could have using attitude control plus wing tilt. Relatively easy to correct position changes. However, could not remain within square the whole time	Precision hover was most difficult part of subtasks. Couldn't really stay within square the whole time, but close to it.	Not able to control as accurately as could have with pitch attitude because wing tilt rate was somewhat too slow for this high drag

TABLE B-VI (Continued)

Case	Ref. Parameters	Pilot-Tilt Mode	$\frac{M_{\delta e}}{\delta_a}$	PR	Selection of Control Characteristics	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
					Pilot Comments					
L15	S3 T=20 deg/sec	A-F3	0.335 0.2?5	5	NOT SELECTED	Quite gust sensitive in all axes. Air taxi maneuver somewhat difficult and requires constant attention. Being able to independently control longitudinal position with thrust vector somewhat helpful. However, tilt rate was too high. Tended to lead position control with an attitude change, then follow up with thrust tilt change.	Maneuvering longitudinally required considerable anticipation and could not stop very accurately at desired point.	Workload quite high due to gust and mean wind effects on high aircraft drag. Thrust vector control helped somewhat but still difficult task.	Precision hover performance fairly good; however, required moderate workload. Used thrust vector control to control longitudinal position during hover	Most objectionable feature was high gust sensitivity in pitch, roll and position control of aircraft. Independent thrust vector control may have helped somewhat but still required considerable pilot workload.
		B-F3	0.329 0.256	3.5		Could perform longitudinal maneuvers quite accurately, stop precisely and hold position fairly well. Made few attitude changes. Almost all control input done using just thrust vector angle. Liked high thrust rotation rate	Could perform quite well. Could maneuver rapidly and stop quite precisely and hold new position relatively well. Some difficulty judging just exactly when to initiate thrust rotation.	Could perform this better than controlling position with attitude changes. Could correct position errors quite rapidly	Could stay within square most of time. Slipped out slightly every now and then, but generally could hover precisely. No problem landing.	Might like a little more attitude stability. Attitude every now and then drifted off and introduced some error. Gust effects on attitude were significant. High rate of thrust angle rotation made it quite easy to control position.
		B-H3	0.329 0.23?	4		Could maneuver longitudinally relatively well and stop precisely, but bothered by large drag, particularly laterally, and by effects of gusts acting on attitude.	Not much difficulty. Could stop precisely and hold position relatively well. However, had to make very large thrust angle changes and tended to induce fair amount of attitude motion.	Could hold longitudinal position quite well. Can perform task better with ITVC than without it.	Can hover relatively well and land OK. Bothered somewhat by roll attitude response.	Disliked attitude response to turbulence and high drag. In general, ITVC helped; could perform task relatively well. Thrust rotation rate adequate.
L17	S2 T=5 deg/sec	B-F3	0.335 0.335	5	NOT SELECTED	Could perform air taxi quite precisely. Although at times desired high thrust rotation rate. Could hold velocities relatively well and stop and hold hover position.	Moderately difficult because of lead time involved in making inputs to arrest motion. Difficult to predict when to initiate corrective inputs	Generally not too difficult. Felt it was easier with ITVC than with attitude. With ITVC didn't disturb attitude so much as attitude was lightly damped, responsive to gusts. Like higher thrust rotation rate.	Not too difficult, could perform accurately with this thrust rotation rate. Vertical landing OK. Some interaction between pitch and roll dynamics.	Disliked lightly damped attitude response and slow rate of thrust rotation.
L18	S2 T=10 deg/sec	A-F4	0.329 0.256	5.5	NOT SELECTED	Attitude very lightly damped, quite sensitive to gusts. Fairly high workload for air taxi to control gust disturbances. Some deterioration in heading and altitude control because of attention on attitude.		Not too difficult because of low drag, however, constant attention is required to maintain pitch and roll control	Precision hover performance fairly well but requires constant control effort to offset gust disturbances on attitude.	Most objectionable features are gust disturbances and lightly damped pitch and roll dynamics. ITVC some aid longitudinal maneuver.
		B-F2	0.3?? 0.249	?.5		Longitudinal air taxi fairly easy. Could maneuver fairly well, hold velocities and stop and hover at desired point. Pitch requires some attention because it was lightly damped. ITVC improvement, without it would have excited attitude motion because of lightly damped dynamics.	Could stop and start quickly, maintain higher velocities and stop abruptly without too much difficulty.	Not difficult. Excited some attitude motion, but in general could hold hover position relatively well. ITVC certainly helps.	Not difficult. Could hold position. During landing had to control pitch and roll fair amount. Again ITVC helped. Some interaction between pitch and roll	Objected to lightly damped attitude dynamics ITVC helped this configuration
L19	S2 T=20 deg/sec	A-F3	0.333 0.333	4	NOT SELECTED	Could maneuver precisely, stop without too much difficulty and hold hover position. Adequate thrust rotation rate. Attitude not too well damped, would have excited attitude more without ITVC since only small attitude corrections needed.	Could stop and start precisely using ITVC	Also not difficult. Could hold hover position quite accurately while controlling attitude disturbances.	Hover not too difficult. Could maintain position within square at all times. Attitude oscillations did require some attention. Landing no problem. A little interaction between pitch and roll, but nothing major.	Felt pitch and roll could use a little more SAS. ITVC helped a good bit
		B-F3	0.338 0.332	5.5		Longitudinal maneuver performed relatively well. Quite tender to disturb attitude and that would affect position. Noticed a fair amount of coupling between thrust angle and attitude changes. Work load considerably high.	Somewhat difficult to stop precisely and then hold new position in presence of attitude disturbances. Noticed some significant inputs to pitching moment due to thrust rotation.	ITVC improved performance. Could hold position quite precisely.	Precision hover and landing not too difficult. Lateral control affected ability to control longitudinally.	Objected primarily to lack of attitude damping. Thrust vector rate was high, but needed it. ITVC definite asset.
L110	S1 T=20 deg/sec	A-F3	0.316 0.242	4	NOT SELECTED	Air taxi not too difficult. Could maneuver with desired velocities and stop precisely. Didn't have too much difficulty monitoring thrust angle and display in control of position.	Somewhat more difficult. Had tendency to overshoot desired stopping point, but again could be performed adequately.	Got into some difficulty in that thrust rotation was over-controlled, perhaps thrust rotation rate was too high.	Hover and landing not difficult.	Somewhat difficult to monitor both thrust angle meter and display during quick stop and turn maneuver. Generally could perform tasks fairly well and switching attention didn't present problem.
L111	S1 ? = 2.0 deg/in ? = 1.0 rad/sec²	A-F3	0.3?? 0.242	3.5	NOT SELECTED	In air taxi could control position and velocity quite precisely. Stop accurately and hold position with no difficulty. Didn't make any pitch attitude control inputs. Acceptable control mode.	Could start and stop very precisely and quickly without difficulty. Noticed some larger attitude changes as speed built up, but learned to essentially neglect them and concentrate on position control.	Not difficult, although did correct for some attitude changes and once momentarily lost control of position. Kind of difficult to control attitude precisely.	Could hold position very precisely. Little attention to attitude, just controlled position. Vertical landing no difficulty.	Kind of difficult to control attitude, but requires little control as it is quite stable. Position control very easy, can control quite precisely, but might like a little more stick sensitivity.

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{N_{\delta_e}}{I_{\theta_e}}$	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Turn-Over-a-Spot	Pilot Comments: Precision Hover, Vertical Landing, Secondary Dynamics	Pilot Comments: Overall Evaluation
1112	BC1 $Y_{\theta} = 5.0$ deg/in. $M_{\delta_E} = 1.0$ rad/sec^2	B-FB	K.A.[1] 0.282	3	NOT SELECTED	Easy to perform precisely and hold velocities accurately, stop precisely and hold hover position with no problem.	Not difficult, can develop large velocities and stop very abruptly with precision. Develop some small attitude oscillations, but just ignored them.	Not difficult to control hover position, but when turning relative to mean wind have to correct for pitch motion; this distracts slightly from position control.	Hover control easy, can hover and land precisely.	Attitude control during turns can be somewhat difficult, although there is a learning process. Very easy to control position. Like thrust vector sensitivity.
1113	BC2 $Y_{\theta} = 10.0$ deg/in. $M_{\delta_E} = 1.0$ rad/sec^3	B-FB	K.A.[1] 0.242	3.5	NOT SELECTED	Not difficult to maneuver and stop precisely. Can hold desired velocities without difficulty. Thrust tilt control sensitivity has gotten somewhat high, notice attitude motion following thrust rotation.	Can stop precisely. Can build up large velocities and arrest them very abruptly and precisely. High control sensitivity induces some attitude motion.	Task somewhat difficult. Position control no problem, but does make have some difficulty in controlling mean wind effects on attitude. Must share attention between attitude and longitudinal position.	Precision hover and landing no problem.	Thrust rotation control sensitivity somewhat high, causes some attitude motion and tends to induce errors in position. Generally can control longitudinal position quite precisely.
1114	BC4 $Y_{\theta} = 5.0$ deg/in. $M_{\delta_E} = 1.0$ rad/sec^3	B-FB	K.A.[1] 0.285	10	NOT SELECTED	Can't really control it. Attitude changes are too high frequency to follow with thumb switch. When trying to reduce large attitude errors position errors get large. Can't control attitude.	Can't perform quick stops.		Can't hover and tend to lose control quite often. Tend to get confused with inputs and can't coordinate inputs well enough. Practice doesn't seem to help.	Inconsistencies between direction that thumb switch pushed to change attitude and direction that control stick pushed to correct for position errors. Can't control sufficiently well to avoid inducing large position disturbances
1115	BC? $Y_{\theta} = 5.0$ deg/in. $M_{\delta_E} = 1.0$ rad/sec^3	B-FB	K.A.[1] 0.395	10	NOT SELECTED	Effectively uncontrollable. Can probably stabilize it and not lose control during hover, but when maneuvering the accelerations in position induce such large attitude changes that can't control them rapidly enough.	Difficult to control attitude in any high frequency sense with this control arrangement.		Large attitude changes induced when attempting to hold hovering position. Can't correct attitude rapidly enough and stabilize it well enough to control with any precision or even to retain control of aircraft.	Eventually get into a large attitude oscillations and lose control, even just at hover. Extremely difficult to control attitude and stabilize it

TABLE B-VII

PILOT COMMENTS FROM THE STUDY OF LONGITUDINAL AND LATERAL RATE-COMMAND/ATTITUDE-HOLD CONTROL

Flying Qualities Results Given in Table A-VIII

Case	Conf. Parameters	Pilot-Sim. Mode	$\frac{M_{\delta_e}}{L_{\delta_a}}$	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
LR1	RCI $M_q = -2$ $M_\phi = -8$	A-F3	0.812 0.975	7.5	Selected to gain control of attitude oscillations and also get desired response.	Very difficult to perform because of large attitude oscillations. Difficult to stabilize pitch and roll, couldn't perform task precisely. Got into some relatively large attitudes.	Same problem. Couldn't stop quickly or precisely and very difficult to control attitude within desired limits.	Couldn't perform precisely because of difficulty in controlling pitch and roll attitude. Did use the wing tilt control to small extent.	Hover was easiest of all tasks, but drifted around. Unquestionably the roll dynamics affected pitch control and vice versa.	Objectionable features - large oscillatory motions in pitch and roll and the lags in response to control inputs.
LR2	RCI $M_q = -2$ $M_\phi = -40$	B-F3	2.408 2.140	4.5	Selected to get pitch and roll rates needed.	Could perform this maneuver fairly well but a high frequency oscillation in pitch and roll was annoying. Too high frequency to control and it affected precision. Still annoyed somewhat by sluggishness in roll response.	No problem with longitudinal quick stop, except for annoying high frequency oscillation; however, lateral quick stop difficult to perform precisely because of sluggishness in roll.	Could perform task fairly well, although the high frequency attitude oscillations were annoying. Used some wing tilt control.	Hover and landing not particularly difficult.	Objectionable features - High frequency oscillation in pitch and roll. Also, roll sluggishness.
		B-F6	3.414 3.408	4.5	Selected to overcome the lags in pitch and roll response	X-maneuver no difficulty. Y-maneuver also not too difficult. Had to avoid building up rates which were too large because it was difficult to attenuate them due to lag in roll response	X-quick stop quite difficult. Couldn't stop precisely and hold position easily. Tended to overshoot and then oscillate back and forth.	Didn't perform task particularly well - had difficulty holding position. Attitude lags might have been a problem. May have been overcontrolling somewhat. Used wing tilt control a fair amount.	Hover not difficult. Vertical landing also no problem. No interaction.	Objectionable features - lag in attitude response and the fact that initiated changes when attention diverted from display.
LR3	RCI $M_q = -4$ $M_\phi = -8$	A-F3	0.944 0.904	8	Selected sensitivity to minimize PIO tendencies.	Required considerable attention because of difficulty in stabilizing commanded attitudes. Required considerable lead compensation to stabilize and anticipation of desired stopping point to arrest velocities. Ability to remain within ground track rather poor because of attention required to control heading. Heading and altitude control deteriorated. Control deflections had to be very small and low in frequency to avoid getting into PIO situations.	Difficult because of difficulty commanding large rapid attitude changes. Needs more rate damping.	Required considerable concentration because of difficulty in maintaining pitch and roll control. Very little wing tilt required.	Hover only moderately difficult but some difficulty establishing a precise hover position.	Most objectionable feature was large amount of lead compensation required to control and stabilize attitude. Had considerable tendency toward PIO's, particularly in pitch.
		B-F3	0.954 0.594	5	Selected to get control of attitude oscillations and develop desired pitch and roll rates.	Could perform task with only moderate precision, attitude oscillations made it difficult to stabilize on ground track precisely and stop precisely.	Again found it difficult to stop precisely and roll out as precisely as desired because of oscillatory pitch and roll response.	Generally able to do this alright. Wing tilt control used a fair amount.	Not too difficult, but again a fair amount of pitch and roll oscillations. Very little interaction.	Objected to oscillatory pitch and roll characteristics.
LR4	RCI $M_q = -4$ $M_\phi = -40$	A-F3	3.354 3.340	2	Selected to get necessary pitch and roll rates	No problem, could perform precisely. Very agreeable case.	No problem, could perform precisely, no undesirable attitude oscillations.	Not difficult. Did use wing tilt control to a small extent.	Neither hover nor landing was difficult. Both performed precisely, although had a little difficulty in hover, maybe because of high sensitivities. Difficult to stabilize on given position.	No objectionable features. Good case.
LR5	RCI $M_q = -6$ $M_\phi = -12$	B-F3	1.792 1.526	4	Selected to get attitude rates desired and also to help control slight oscillatory tendency in pitch and roll	No problem longitudinally. Laterally generally no problem except some tendency to oscillate when rolling out, although these oscillations are relatively easy to control.	No problem in longitudinal; however, when making lateral quick stop have tendency to develop some undesirable oscillations when trying to roll out rapidly.	No problem. Did use wing tilt control to some small extent during turn.	Precision hover and vertical landing performed precisely. No interaction	Objectionable features - Tendency to oscillate when making abrupt roll changes.
LR6	RCI $M_q = -6$ $M_\phi = -40$	B-F3	2.588 2.208	2.5	Selected to get attitude response desired.	Could perform maneuver quite well. Attitude very stable, no attitude oscillations noticeable. Didn't get into large attitudes. In general could perform fairly well.	Same story, although attitude seemed a little sluggish. Seemed to have to anticipate things a bit more and couldn't make large rapid changes in roll.	Not difficult because attitude quite stable. Seemed to have some trouble with lags in response to control commands. Used wing tilt control to slight extent.	Hover and vertical landing no difficulty. No interaction between axes.	Objectionable features - perhaps slight sluggishness in pitch and roll, especially roll. However, attitude very stable, highly damped.
		B-F6	4.182 4.696	3.5		Could perform relatively well. Bothered somewhat by sluggishness in control response. Also had to concentrate to avoid developing attitude errors.	Couldn't perform particularly well. Annoying lag in attitude response. Have to pay close attention to attitude	Not too difficult. Made significant use of wing tilt control.	Could hover fairly well. Landing not difficult. No real interaction between pitch and roll.	Lags in pitch and roll response affected control. Also attitude errors integrate rapidly when attention is diverted.
LR7	RCI $M_q = -8$ $M_\phi = -40$	A-F3	4.044 2.240	4	Set control sensitivity to achieve desired response to control inputs.	Fairly easy to perform although anticipation was required to stop at desired hover point due to low translational drag. Could hold heading and altitude quite well during air taxi maneuver.	Performance fairly good although could not achieve real rapid attitude changes without large control inputs.	Had a little difficulty trying to maintain hover position because of concentration required to hold attitude. Very little wing tilt control required.	Hover and landing performance very good and required very little workload or control motions.	Most objectionable feature was if a control input were held, it resulted in attitude changes if attention directed elsewhere. May need more training with this control system.
LR8	RCI $M_q = -10$ $M_\phi = -50$	A-13	3.950 3.344	3	Responded almost as rate command system so set sensitivity to achieve desired rate response.	Relatively easy and performance was quite good. Could hold heading and altitude quite well during maneuver and control deflections relatively small and low frequency.	Slightly annoying, couldn't change attitude as rapidly as desired without rather large control inputs.	Wasn't too difficult. Very little wing tilt control required, but did require concentration because of low drag.	Precision hover relatively easy. Performance good and gust disturbances hardly noticeable.	Slightly objectionable feature was attitude control during quick stops.

TABLE B-VII (Concluded)

Case	Config. Parameters	Pilot	ω	PR	Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
					[illegible] Comments					
1S8	30%, $M_q = -10$, $M_\phi = -50$	S-P3	5.532, 6.500	3	Selected to overcome sluggishness in pitch and roll response.	Not at all difficult. Didn't get into any large attitude changes and didn't have any problem holding velocity and stopping at desired point.	Lateral quick stop no problem. Could stop precisely. Longitudinal quick stop somewhat more difficult; had a little difficulty stopping but didn't tend to oscillate too much.	Could perform relatively well. Not too difficult. Used wing-tilt control to some extent.	Hover and vertical landing not difficult.	Still a little sluggishness in attitude response. Everything well damped. Bothered by fact that when looking at heading indicator, tended to drift away in attitude.
1S9	30%, $M_q = -2$, $M_\phi = -16$	S-P3	1.792, 0.564	4.5	Selected to get control of attitude oscillations and to get desired attitude response.	Not too difficult. Some annoying tendency to oscillate in pitch and roll; however, these are low frequency.	Generally not too difficult. Attitude oscillations, although low frequency, large enough amplitude to affect ability to control.	Difficult. Must account for high drag with wing tilt control. Attitude oscillations make difficult to concentrate on position.	Hover and vertical landing not too difficult.	Oscillatory attitude characteristics and high drag which makes it difficult to turn over spot precisely are objectionable.
1S10	30%, $M_q = +2$, $M_\phi = -25$	S-P3	2.152, 1.668	5	Selected to get rate of response desired to overcome effects of attitude stabilization.	Somewhat difficult to perform because of higher frequency oscillations in pitch and roll. Not large enough amplitude or low enough frequency to affect position, but were a distraction and made attitude control a problem.	Difficult to stabilize attitude at times following roll-out during lateral quick stop.	Some difficulty due to distractions in attitude, high frequency oscillations. Wing tilt control used a good bit.	Couldn't hover too precisely due to high frequency attitude oscillations. Vertical landing no problem. Some interaction between pitch and roll dynamics.	Fairly continuous, high frequency oscillations in attitude objectionable
1S11	33%, $M_q = -4$, $M_\phi = -16$	S-P3	1.688, 1.392	3.5	Selected to get desired attitude rates	Generally could perform maneuvers quite precisely. Nice response in pitch and roll. Possibly slight tendency toward low-level oscillations, but presented no problem. Good attitude characteristics.	No real difficulty performing. Could stop abruptly. Attitude quite controllable, predictable.	Performed reasonably well. Could concentrate on position without developing large attitude errors. Wing tilt control used a great deal.	Hover and vertical landing no problem. No interaction between pitch and roll.	Objectionable features were high drag in pitch and roll and perhaps some lack of damping
		S-P2	2.175, 2.474	5	Selected to reduce tendency to excite rather lightly damped, high frequency oscillations in pitch and roll.	Could perform relatively well but encountered same problems because of lightly damped, high frequency oscillations in pitch and roll. Had to be careful not to excite them.	Could perform with adequate precision, but there was a lot of roll activity during lateral quick stop. Attitude is almost constant oscillation during task.	Could perform with adequate precision. However, pitch and roll were in almost constant oscillation. Had to be quite careful not to excite fairly large attitudes while diverting attention to heading. Used wing tilt control good bit.	Hover and landing not difficult. Possibly some interaction between pitch and roll.	Lightly damped, high frequency oscillations in pitch and roll were disagreeable. Oscillations affected ability to control a good deal.
1S12	30%, $M_q = -4$, $M_\phi = -25$	S-P2	2.534, 2.244	3	Selected to get the attitude response needed to overcome attitude stabilization.	Not difficult except for effects of rather large drag. Good attitude response characteristics, well damped. No oscillations and didn't get into unexpected attitudes.	Generally could perform fairly well, although high drag held down forward velocity	Handled this alright. Have to take it slow because of high drag and have to be careful with wing tilt. Attitude presented no distraction.	Hover and vertical landing not difficult.	High drag objectionable, but attitude characteristics very good.
1S13	30%, $M_q = -6$, $M_\phi = -16$	S-P[illegible]	1.632, 1.372	3	Selected to get desired rates of change in pitch and roll.	Not particularly difficult to maneuver. Attitude quite predictable, well damped. Very slight tendency toward some low frequency oscillations but no problem controlling.	Generally no problem, although probably could have used a little more sensitivity in roll. Sensitivity a compromise between that needed to roll out in lateral quick stop vs requirements for hover	Not difficult. Took time and used wing tilt control extensively.	Hover and landing not difficult. No real interaction.	Only objectionable feature might be high drag and slight tendency toward low frequency oscillations in pitch and roll.
1S14	30%, $M_q = -[illegible]$, $M_\phi = -2[illegible]$	S-P[illegible]	2.205, [illegible].517	3	Selected to get desired attitude rates	No difficulty regarding attitude control. Good attitude characteristics, but high drag tends to make it somewhat difficult to maneuver precisely.	Attitude control great. Generally can perform quick stop precisely	Good attitude characteristics, but again is difficult because of large drag. Have to take it slow and use wing tilt control good bit	Hover and vertical landing no problem. No interaction between pitch and roll.	Objectionable feature: Effect of turbulence on high drag characteristics. Excellent attitude characteristics
		S-P[illegible]	3.[illegible], [illegible]	4.5	Selected as compromise between getting desired rate of response and avoiding excitation of oscillatory dynamics	Somewhat not too difficult, did have oscillatory tendency in pitch requiring concentration. Could hold velocities fairly well	In general, could perform quick stops alright but tended to get into pitch and roll oscillations.	Rather difficult. Had tendency to develop unwanted attitudes in both pitch and roll because of oscillatory attitude response. Immediately develop unwanted attitude when attention diverted	Hover and landing not difficult. No real interaction	Oscillatory pitch and roll response objectionable. Tended to develop unwanted attitudes rather easily
1S15	30%, $M_q = -10$, $M_\phi = -5$	S-P[illegible]	3.7[illegible], [illegible].22[illegible]	3	Set to achieve desired response in pitch and roll for maneuvering task.	Fairly good performance. Could stay quite well within ground track. Used pulse-type control inputs to command desired pitch and roll. Control inputs relatively small and low frequency	Not too difficult but required rather large attitude changes to get quick-stop type motion	Required considerable attention to offset gust and yaw wind effects on drag. This required considerable wing tilt control in turn	Hover relatively easy, but gust disturbances required continuous control. Performance quite good	Configuration relatively good. Only slightly objectionable features were yaw wind and gust effects on position response of aircraft
		S-P2	5.01[illegible], 5.5[illegible]	3	Selected to overcome sluggish pitch and roll response	Not too difficult. Can perform precisely without excessive attitude changes. Kind of difficult to get this moving, but large drag helpful in arresting velocity	Quick stop not too bad. Had a little trouble with quick stop in stopping at desired point without oscillation in position.	Some difficulty, although didn't introduce particularly large position errors. Had to coordinate wing-tilt control with direction	Hover and landing not difficult. No interaction.	Objected to sluggishness in pitch and roll even with large sensitivities. Everything quite well damped

TABLE B-VIII

PILOT COMMENTS FROM THE HEIGHT CONTROL STUDY OF THE INTERACTION BETWEEN HEIGHT VELOCITY DAMPING AND THRUST-TO-WEIGHT RATIO

Flying Qualities Results Given in Table A-IX

Case	Conf. Parameters	Pilot-Sim. Mode	Z_{δ_c}	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Precision Hover, Landing Sequence and Secondary Dynamics	Pilot Comments: Overall Evaluation
HZ1	BC1 $Z_{w_a}=Z_{w_g}=0$ T/W=UL	A-FB	3.46	9	Set height control sensitivity in an attempt to stabilize altitude.	Very difficult because of difficulty in controlling altitude. Altitude was very, very lightly damped and required extreme concentration to gain even minimal altitude stability. As a result, the remainder of the task suffered considerably.	Also difficult to perform because the large altitude changes produced altitude errors which were difficult to control and often resulted in PIO-type situations in altitude.	Hover difficult because of altitude control. Had difficulty holding altitude within ±15 ft of the desired level. Altitude control activity high.	Most objectionable feature was the lack of damping in altitude. Intense pilot compensation was required to retain control.
		B-FB	3.14	7	Selected in an attempt to get height under control.	Quite difficult, can't perform the task as precisely as desired because have to pay so much attention to height control. Altitude varies ±20 ft upward to ±40 ft. Difficult to keep under control.	Cannot be performed precisely because must pay so much attention to height.	Could perform fairly well. Didn't disturb height too much while hovering. Configuration was good enough such that could hold hover position fairly well. The landing sequence performed reasonably well, at least in height; however, neglected hovering position somewhat. Could land it safely.	Definitely needs more height damping.
		B-MB	3.03	7	Selected in an attempt to gain control of altitude oscillations.	Could maneuver longitudinally without too much difficulty, however, height oscillated ±30 ft. Lateral maneuvering was difficult.	Performing lateral quick stops was quite difficult, tended to have altitude go up to 100 ft or more.	Could hold altitude within ±10 ft in hover. Definite interaction between height and particularly lateral control. Could change altitude, but tended to oscillate a fair amount about it.	Needs more height damping.
HZ2	BC1 $Z_{w_a}=Z_{w_g}=-0.125$ T/W=UL	A-FB	2.98	4	Set height control sensitivity to get desired altitude response for air taxi and landing sequence.	Altitude control fairly good, could devote attention to control of other axes during the air taxi and quick stop maneuvers. Relatively easy and very little wing tilt trim was required during turn.		Precision hover required very little control activity and altitude could be held fairly well. The landing sequence maneuver required a little anticipation to stop at desired altitude, but otherwise was not too difficult.	A little more altitude damping needed to make it a satisfactory configuration.
		B-FB	3.12	4.5	Selected to get desired altitude response.	Could perform task while holding height fairly well, although height required attention. Held height within say ±5 ft.	Could hold height if considerable amount of attention paid to it. Probably quick stop performance suffered somewhat and height tended to slip away.	Could hover quite accurately. Didn't have any problem holding height. Hover position wasn't affected too much by turbulence, consequently, there was little to disturb height, no large attitude changes necessary to correct hover position. In landing sequence, going from 40 ft down to 20 ft, had difficulty arresting the descent rate and holding it. Had a tendency to overshoot desired altitude. Could land without too much difficulty, but had to do it cautiously.	Think Z_w level is a little too low, would like to be able to take attention off height a little more. Can't hold altitude much better than ±5 ft at best.
		B-FB	2.57	4	Selected to get desired rate of response in height.	Generally could perform this task fairly well, at least longitudinally. When maneuvering laterally, developed some height oscillations which were somewhat difficult to damp out. Paying attention to these and trying to get height under control did detract from ability to perform the lateral maneuver.	Generally could perform these relatively well. Had some trouble with the lateral quick stop and the coupling into height. Would like to see a little more height damping.	No problem hovering and holding hover altitude. Could come down and stop fairly well at 20 ft and then come back up to 40 ft. Had to lead inputs somewhat, but this wasn't any great problem. Some interaction between height and control of roll.	Didn't like tendency to build up height oscillations when attempting to maneuver laterally. Had to pay attention to height but the damping was just slightly inadequate.
HZ3	BC1 $Z_{w_a}=Z_{w_g}=-0.25$ T/W=UL	A-FB	3.04	3	Selected height control sensitivity to obtain desired altitude response for takeoff and landing.	Air taxi was relatively easy as altitude required only moderate amount of attention to hold during the maneuver. Air taxi required relatively small pitch and roll changes, however, due to low drag, stopping position had to be anticipated.	Had no particular problems and altitude control was no problem as long as height control was coordinated with large attitude changes.	Control motions and pilot effort during precision hover were very low. Had very little trouble arresting sink rate during the landing sequence and the subsequent climb back to 40 ft.	A little more height damping might be desirable but this level is quite adequate.
HZ4	BC1 $Z_{w_a}=Z_{w_g}=-0.4$ T/W=UL	A-FB	3.50	2	Selected to get desired response to collective inputs for changing Altitude.	Air taxi was relatively easy because very little attention was required to control altitude.	Quick stop maneuver quite easy	Precision hover required virtually no inputs on the altitude control to maintain the altitude within a few feet of the nominal hovering altitude.	Very good height control, has adequate damping.
HZ5	BC1 $Z_{w_a}=Z_{w_g}=-0.05$ T/W=1.02	B-MB	3.05	7	Selected in an attempt to control altitude oscillations.	Developed coupling between height and both longitudinal and lateral axes when attempting to maneuver. Seemed to have difficulty holding height during the longitudinal maneuver.	During the longitudinal quick stop just about touches down because of the low thrust and lack of damping. Height was consistently going into relatively large oscillations, 20 ft or so.	This wasn't too bad. Could stabilize height fairly well and keep hovering position under control quite well. During landing sequence almost touched down during descent to 20 ft. Had to be very careful because of the low control power. Was able to stabilize fairly well after desired altitude achieved. Needs more thrust and more damping. Definite interaction between the height dynamics and roll and pitch dynamics.	Objectionable feature is the distinct lack of height damping and low thrust.
HZ6	BC1 $Z_{w_a}=Z_{w_g}=-0.125$ T/W=1.02	A-FB	3.0	7		Had adequate thrust for takeoff but had difficulty stopping at desired maneuvering altitude of 40 ft. Had some problems controlling altitude during the air taxi and turn-over-a-spot maneuvers.	Control of altitude required considerable pilot attention in quick stops.	Hovering performance fairly good, but required some attention to control altitude. Had a great deal of difficulty in arresting sink rate during the descent to 20 ft. Thrust was clearly quite inadequate and the configuration lacked height damping.	Aircraft needs both increased thrust and increased height damping.
HZ7	BC1 $Z_{w_a}=0$ $Z_{w_g}=-0.25$ T/W=1.02	A-FB	3.0	6		Climb-out following takeoff was very slow due to lack of thrust. Had some difficulty stopping and maintaining desired maneuvering altitude at 40 ft. Air taxi required considerable pilot concentration on altitude control. Somewhat difficult to stay within ±5 ft of the desired altitude.	Particularly difficult due to the upsets in altitude. During the lateral quick stop briefly touched down.	Precision hover not too difficult after the desired altitude was stabilized, but stabilizing this altitude was somewhat of a problem and required considerable effort. Arresting sink rate during the landing sequence maneuver required that only small sink rates could be developed.	There were two equally objectionable features: (1) the lack of thrust for arresting sink rates and climbing out and (2) the insufficient altitude damping. Considerable effort required to avoid developing high sink rates.
HZ8	BC1 $Z_{w_a}=$[illegible] $Z_{w_g}=0$ T/W=1.02	A-FB	3.0	6		Configuration very sluggish during liftoff, could not establish very high rate of climb; however, had no difficulty at all establishing desired altitude. During the air [illegible] air taxi had no problem controlling altitude	Altitude was upset a little more and did notice a limitation on thrust in arresting sink rate.	Hovering performance was very good and was not bothered by lack of either thrust or altitude damping. During landing sequence had to be careful not to develop too high a sink rate, but didn't have too much difficulty arresting sink rate as long as care was used. Climb out again to 40 ft was very slow and sluggish.	Most objectionable features were (1) lack of thrust which was particularly annoying during climb out and (2) annoyance in arresting sink rate, although this problem was not too severe.

TABLE B-VIII (Continued)

Case	Config. Parameters	Pilot-Sim. Mode	Z_{δ_c}	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Precision Hover, Landing Sequence and Secondary Dynamics	Pilot Comments: Overall Evaluation
HZ9	BC1 $Z_{w_a}=0$, $Z_{w_g}=0.35$ T/W=1.02	B-FB	3.0	4		Had to pay fairly close attention to height control when maneuvering. Had to lead inputs a fair amount in order to arrest descents and had to be careful about building up descent rates that were not too large. Couldn't take attention off height control. Although I could perform the maneuvers fairly well, it affected their precision somewhat. Also, don't think height held any better than about ±10 ft on the average, maybe somewhat less.	Required considerable attention to control altitude.	Hover was not too difficult to perform and could stabilize attitude fairly well. Had difficulty going down to 20 ft and stabilizing there, tended to oscillate up and down. Also, had to be very careful with collective inputs. Significant amount of time before reaching desired 20 ft position. Could land safely, however.	Would prefer to see a little more Z_w and also more thrust.
HZ10	BC1 $Z_{w_a}=Z_{w_g}=$ -0.25 T/W=1.02	A-FB	3.0	4		Adequate thrust for takeoff. Had no problem stopping at desired hovering altitude. All constant altitude maneuvers were relatively easy to perform. Did not have to concentrate much on altitude and held altitude relatively constant.	No problems.	Precision hover performance was very good and there was very little control activity required. Thrust was slightly deficient when attempting to arrest sink rate so had to anticipate the desired altitude while descending by applying thrust with anticipation.	Only slightly objectionable feature was the limitation on thrust which was noticed only when arresting sink rates.
HZ11	BC1 $Z_{w_a}=Z_{w_g}=$ -0.4 T/W=1.02	A-FB	3.0	5		Climb out following takeoff was very slow as there was inadequate thrust to develop any significant rate of climb. However, damping seemed quite good so had no trouble stopping at desired maneuvering altitude. Altitude control was quite easy during all of the constant altitude maneuvers, including air taxi and turn-over-a-spot.	No problem controlling altitude.	Hover performance good, little effort required. Didn't seem to have much trouble arresting sink rate during the landing sequence. However, had difficulty climbing back up to 40 ft, there was just inadequate thrust available. Landing was not particularly difficult as long as sink rate wasn't allowed to get too high.	Biggest objections were (1) lack of thrust for developing suitable climb rates for taking off and climbing to desired altitudes and (2) inadequate thrust for arresting high rates of sink.
		B-FB	3.0	4		No difficulty, quite easy to hover and maneuver and to stop precisely both vertically and laterally. Could hold height quite accurately while doing this. Little attention required.	Can perform without difficulty and can go to relatively large attitudes without having altitude affected significantly.	No difficulty, can hover precisely and hold altitude without difficulty. In landing maneuver can ease down to 20 ft without too much difficulty. Must perform this task relatively slowly because can't arrest large sink rates; however, the large Z_w aids in performing task. Very difficult to climb back up to 40 ft altitude because of low thrust. Can land quite easily, but again have got to do it relatively slowly.	Only objectionable feature is that it is very difficult to climb to any altitude. Response is much too slow and have some difficulty arresting sink rates, but this is not a significant problem.
		B-MB	2.98	5	Selected to get desired response to control inputs in height.	Could maneuver quite well. Some coupling between height and roll inputs, but generally height very stable, very well damped. Only complaint with height control is lack of thrust. It takes a long time to climb out. However, can descend and arrest descent very abruptly and precisely.	No problem, but during the lateral quick stop did couple in some height motion.	No problem. Landing sequence not difficult to perform, but annoyed by inability to climb out as quickly as desired. Much too sluggish in climbing.	Only objectionable feature is lack of thrust which restricts rate of climb, but well damped and can arrest descents precisely.
HZ12	BC1 $Z_{w_a}=Z_{w_g}=$ -0.005 T/W=1.05	B-MP	3.07	6.5	Selected primarily in attempt to control height oscillations.	Could perform the longitudinal maneuver fairly accurately and hold hover within ±10 ft. Lost precision in lateral maneuver because of concentration required on holding height. Definite interaction between height control and ability to control laterally.	Again longitudinal was not too bad. Laterally didn't build up too many large errors but still feel that height control is much too poorly damped to control adequately.	Hover wasn't too difficult. Height remained in constant oscillation, but not to particularly large amplitudes or as large as they were during the maneuvering portions of the tasks. Could descend to about 20 ft and hover there with relatively small altitude oscillations and then go back up to 40 ft. Height dynamics definitely affected ability to control lateral position.	Definitely needs more height damping to reduce attention required on height control.
HZ13	BC1 $Z_{w_a}=Z_{w_g}=$ -0.05 T/W=1.05	B-MB	3.01	6	Selected to get desired rate of change of height and to help get the height oscillations under control.	Air taxi not difficult. Holding height within ±10 ft while maneuvering longitudinally, but when maneuvering laterally tended to develop larger height oscillations as much as ±20 ft or so. Think height control did affect ability to perform maneuvering task to some extent. Difficult to stabilize height. Height was in almost continuous oscillation.	Longitudinal quick stops could be performed better than lateral ones, however, in both introduced some upsets in height. These were especially pronounced for lateral quick stop when altitude diverged by about 30 ft. Unfortunately, height was in pretty much constant oscillation during performance of quick stops.	Hover not too difficult. Could keep the height oscillations to within ±5 ft. Had sufficient control power to perform landing sequence, but needed some damping. Had to lead height control to arrest climb and descent rates. Could perform vertical landing safely. Height dynamics did affect ability to control during the lateral quick stop. Tendency to let height diverge and concentrate on the lateral maneuver.	Objectionable feature was the lack of height damping. Control power seemed adequate.
HZ14	BC1 $Z_{w_a}=Z_{w_g}=$ -0.125 T/W=1.05	A-FB	3.0	3		Thrust adequate for takeoff and didn't have too much trouble stopping at the desired altitude following climb out. Height control required a little bit of attention while performing the constant altitude maneuvers, but both thrust and damping seemed to be adequate.	No problem with this task.	Precision hover performance was quite good and required very little attention. During the landing sequence maneuvers seemed to have adequate thrust for arresting sink rate and for climbing back to the 40-ft altitude hover.	
		B-FB	3.0	4.5		Air taxi could be performed reasonably well, but had to pay significant amount of attention to altitude. Tended to drift away and had to correct and lead control corrections to stabilize on altitude.	Could be performed fairly well. Could go to large attitude changes without abrupt changes in altitude. However, again altitude tended to creep off and needed stabilization.	Could hover fairly well but had to pay fair amount of attention to altitude. Had some difficulty stabilizing on new altitudes when descending and in coming back up to 40 ft. Had to lead control inputs to stabilize height. Also had to approach the landing somewhat cautiously.	Didn't feel that altitude could be changed easily enough. Had to be somewhat careful with altitude control. Like to see more height damping.

Case	...f. Parameters	Pilot-Sim. Mode	Z_{δ_c}	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Precision Hover, Landing Sequence and Secondary Dynamics	Pilot Comments: Overall Evaluation
HC14	SC1 $Z_{w_a}=Z_{w_s}=-0.125$ T/W=1.05	B-HO	2.62	3	Selected to get desired height response.	No problem performing maneuver longitudinally; laterally might have excited a little height motion, but apparently height is sufficiently well damped that did not get into any significant height position changes.	Could perform both longitudinal and lateral quick stops fairly well without upsetting height. Height is relatively easy to control, stable.	No problem holding hover position or altitude. No problem performing landing sequence. Could stop abruptly with only a slight amount of compensation. Height position well damped. No real interaction between different axes.	No real objectionable features. Sufficient damping, no apparent lack of control power.
HC15	SC1 $Z_{w_a}=0.$ $Z_{w_s}=-0.25$ T/W=1.05	A-FB	3.0	6		Because of inadequate thrust, takeoff was relatively sluggish, but had no difficulty establishing desired maneuvering altitude. During constant altitude maneuvers performance was fairly good. Lack of altitude damping was not a particular problem. Hovering turn required only a small amount of wing tilt trim.	Upset altitude somewhat but the only deficiency is a lack of thrust for arresting these altitude disturbances.	Precision hover performance was excellent and required very little effort. Damping was fairly good during the landing sequence; the only problem was arresting high sink rates quickly, this required caution to develop only minimal sink rates.	About only objectionable feature seemed to be lack of thrust for arresting sink rates and for developing desired climb rates. Required extensive attention to avoid getting into problems during high sink rates.
HC16	SC1 $Z_{w_a}=-0.25$ $Z_{w_s}=0.$ T/W=1.05	A-FB	3.0	5		Thrust more than adequate for takeoff. Required a little anticipation to stop at desired maneuvering altitude. During air taxi and turn-over-a-spot moderate pilot attention was required to control altitude, but performance was not degraded	Some tendency to upset altitude, but had more than adequate thrust to arrest the motion.	Adequate thrust and damping for precision hover. During landing sequence had adequate thrust to arrest sink rate and did not have to place any limitation on sink rate for fear of not being able to arrest it.	Only moderately objectionable feature was that it could use a little more height damping.
HC17	SC1 $Z_{w_a}=-0.25$ $Z_{w_s}=-0.25$ T/W=1.05	A-FB	3.0	4		Not much difficulty in performing constant altitude maneuvers. Altitude required small amount of attention but seemed to have adequate damping and thrust for maintaining constant altitude.	No altitude control problems.	Precision hover performance was very good and required very little pilot concentration. There was adequate thrust for climbing but stopping at desired altitude required some pilot anticipation.	At this damping level thrust seemed adequate, but a little more height damping would be desirable
		B-FB	3.0	2.5		Could perform air taxi with precision and hold altitude quite accurately. Altitude very stable, easy to correct and generally did not stray much from desired altitude. No need to lead inputs.	Could perform this task easily and precisely and could make fairly large attitude changes without affecting height too much.	Could hover very precisely, very little need to monitor altitude. In the landing maneuver could descend quite precisely to 20 ft and come back up. The vertical response was positively good, didn't seem to lack control power and the damping was more than adequate. No difficulty arresting sink rate, no great need to lead altitude inputs. Could land quite precisely.	No real objectionable features to this case.
		B-HO	3.06	2.5	Selected to get desired response in height.	Maneuvering no problem. Could perform the task precisely and had no real problem with holding height during either the longitudinal or lateral maneuvers.	Could perform these precisely. Did see some decrease in altitude when making very abrupt lateral stops with large roll angles, but easily corrected.	Precision hover no problem. In landing sequence could change altitude very abruptly and stop quite precisely with no noticeable overshoot. Could also climb fairly rapidly.	Might like to see a little more control power, but not much. No real objectionable features.
HC18	SL1 $Z_{w_a}=Z_{w_s}=-0.40$ T/W=1.05	A-FB	3.0	3.5		During takeoff had adequate thrust for climb out. No difficulty stopping at maneuvering altitude of 40 ft. During constant altitude maneuvers altitude required very little effort to control and altitude control was good. Height dynamics seemed well damped and to have a rate-type response.	No problem with task.	Hovering performance good and required very little effort. Could not develop real high rate of climb or rate of descent due to limitation on thrust and/or high damping. A little more thrust would have been desirable to develop higher rates of climb and to insure arresting sink rate during descent.	Only slightly objectionable feature was perhaps being a little sluggish in response in altitude due to the lack of control power.
HC19	SC1 $Z_{w_a}=Z_{w_s}=-0.03$ T/W=1.10	B-HO	3.24	6	Selected to help in stabilizing height oscillations.	Could maneuver longitudinally without too much trouble. When maneuvering laterally introduced a fairly large longitudinal displacement error while concentrating on height. Height required a lot of pilot compensation to stabilize, was in almost constant oscillation up and down, as much as 20 ft.	Longitudinal quick stops performed fairly well while holding height within ±5 to ±10 ft. Lateral quick stops quite difficult because of the lack of height damping.	No difficulty hovering. Could keep height oscillations small while hovering accurately. Could perform landing sequence fairly accurately. Could descend relatively quickly to 20 ft and stabilize and rise again to 40 ft, then land gently. Height dynamics definitely affects ability to control other axes (particularly roll).	Height dynamics objectionable, need more damping.
HC20	SC1 $Z_{w_a}=Z_{w_s}=-0.125$ T/W=1.10	A-FB	3.0	2.5		Had more than adequate thrust for takeoff and had little difficulty stopping at desired altitude following climb out. During the constant altitude maneuvers had to devote only a small amount of attention to the control of altitude.		Precision hover required very little concentration or control activity. During landing sequence maneuver had no difficulty arresting sink rate, however, small amount of anticipation required to stop at desired altitude.	Only improvement desired might be a slight increase in altitude damping. Otherwise configuration is quite satisfactory.
		B-FB	3.0	4.5		In general could perform air taxi relatively well. Did have to pay attention to altitude, however, and make fairly constant corrections. Had to take concentration away from horizontal position a good deal to monitor altitude. Had to lead altitude control somewhat. Would like to see a little more altitude damping. Had adequate control power.	Could perform this maneuver without too much difficulty. Didn't notice a lack of control power and went to relatively large attitudes without affecting altitude too much. Bothered occasionally by the fact that altitude would tend to change unnoticed.	Hover performed quite accurately, but altitude required attention. Landing sequence performed fairly well. Could maneuver vertically at satisfactory rates, but had to lead inputs somewhat when arresting vertical rates.	Would like to see a little more altitude damping, although it is not all that bad. Think control power is adequate.

TABLE B-VIII (Continued)

Case	No. of Parameters	Flight Sim. Mode	Z_{δ_c}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Precision Hover, Landing Sequence and Secondary Dynamics	Overall Evaluation
K220	NC1 $Z_{w_e}=Z_{w_g}=-0.125$ T/W=1.10	B-MB	2.62	3	Selected to get desired height control response.	Not too much difficulty with longitudinal maneuvering. In lateral maneuvers noticed some coupling between altitude and roll. Had to be kind of careful maneuvering laterally because could build up some fairly substantial height variations if not watched closely.	Had to be careful with lateral roll outs to make sure that height wasn't disturbed. Had to watch height closely, definitely some coupling between roll and height.	No problem, could hold height fairly well, ±2 to 3 ft. Could descend to 20 ft and stop rapidly. Some control compensation required, but could stabilize relatively well at desired height and then climb to 40 ft without too much difficulty.	Slight lack of height damping, but seemed to be plenty of thrust.
K221	NC1 $Z_{w_e}=0.$ $Z_{w_g}=-0.25$ T/W=1.10	A-FB	3.0	4.5		More than adequate thrust for takeoff. Had good rate of climb but had to anticipate desired maneuvering altitude a little. During air taxi and hovering turn maneuver general performance was fairly good but had to direct moderate attention to control of altitude.	Tended to upset altitude but had adequate thrust margin to arrest sink rates.	Precision hover performance was very good and required very little effort or concentration. No problem arresting sink rates as there was more than adequate thrust and even didn't have too much difficulty stopping at desired altitude.	Only objectionable feature was a slight deficiency in altitude damping, but thrust seemed more than adequate.
		B-FB	3.0	5		Altitude tended to wander when maneuvering and when performing quick stops. Had to monitor altitude a good bit in order to hold altitude precisely. Could perform the task fairly well.	Performance fairly good, but altitude needed attention and tended to overshoot periodically when making corrections.	Could hover precisely, had to monitor altitude again, but altitude control not too difficult. The landing sequence was performed fairly well. Had some difficulty arresting attitude, some tendency to overshoot desired altitude.	Needs more altitude damping.
		B-MB	2.82	3.5	Selected to get desired height response.	No problem with air taxi. Had to watch height while maneuvering laterally, but could control this to within about ±3 ft.	Had to keep attention on height when making lateral quick stops and make some compensating inputs, but height didn't change rapidly. No problem with longitudinal quick stop.	Hover no problem. In landing sequence could change altitude fairly abruptly and stop without too much difficulty. Had to compensate for overshoots a little but didn't require too much effort.	Maybe would like to see a little more damping, but the case is relatively easy to control.
K222	NC1 $Z_{w_e}=-0.25$ $Z_{w_g}=0.$ T/W=1.10	A-FB	3.0	4		Good thrust for takeoff and developed good rate of climb, stopping at desired altitude was not too much of a problem. Constant-altitude maneuvers required moderate attention to altitude control but performance was fairly good.	These maneuvers upset altitude the most and required the most attention	Precision hover performance was very good and required very little effort. Had no difficulty at all arresting sink rates or stopping at desired altitudes.	Only annoying feature seemed to be attention required to control altitude during constant altitude maneuvers.
		B-MB	2.76	3.5	Selected to get desired height response	No problem with longitudinal maneuvers. Could perform task precisely and hold hover altitude relatively well, ±2 to 3 ft. Had to pay somewhat more attention to height during lateral maneuvers.	Could perform fairly well, introduced slightly larger height errors during lateral than longitudinal maneuvers, but height didn't change rapidly and it was reasonably easy to correct.	Hover no problem. Could descend relatively rapidly and arrest descent accurately and quickly. Had to make some small compensating control inputs but fairly easy to do.	Might like to see a little more height damping, but this is not a bad case.
K223	NC1 $Z_{w_e}=Z_{w_g}=-0.24$ T/W=1.10	A-FB	3.0	2.5		More than adequate thrust for takeoff and had no difficulty at all stopping at desired altitude following climb out. Altitude control during all of the constant altitude maneuvers was relatively easy and required very little effort	No problems.	Precision hover performance was very good and required very little effort. Both thrust and height damping seemed adequate. During the landing sequence maneuvers had no difficulty arresting sink rate or stopping at desired altitude.	Good configuration
		B-FB	3.0	4		Air taxi could be performed with fair precision, although it would have been aided by a little more altitude damping. Altitude tended to creep away periodically. Altitude control required some lead. However, most disagreeable factor was that it tended to drift off when attention not paid to it almost constantly.	Could perform this task relatively well. Could go to fairly large attitude angles without having altitude change abruptly, but altitude tended to drift away.	Not difficult, but had to pay attention to altitude. Could change altitude relatively quickly and stop without too much difficulty. Needed to lead inputs a little but not a great deal. Landing done precisely. Generally, had no complaint about ability to maneuver vertically, but was bothered by lack of altitude stability. Don't think altitude held any better than about ±5 ft or more	Needs a little more altitude damping.
K224	NC1 $Z_{w_e}=Z_{w_g}=-0.40$ T/W=1.10	A-FB	3.0	2.5		Air taxi maneuver and turn-over-a-spot relatively easy to perform and had relatively good performance. Control of altitude required very little attention. Height seemed adequately damped and to have adequate thrust for control	Relatively easy to perform.	Precision hover required very little effort and could control all axes quite well. Adequate thrust for climbing and changing altitude and arresting sink rate. There may have been very small amount of anticipation required to stop aircraft at desired altitude	Good configuration
K225	NC4 $Z_{w_e}=Z_{w_g}=0$ T/W=1.10	A-FB	3.0	10	Set range of sensitivities in an attempt to obtain closed-loop control over altitude.	Had an extremely difficult time controlling altitude, it required extreme anticipation to arrest vertical motion and at times got into violent PIO's that usually resulted in hitting the ground. Found it next to impossible to perform the task because when attention diverted from strictly altitude control lost altitude control through either pure divergence or PIO tendencies.			It is mandatory that this configuration have more height damping. Control would be lost during some portion of the required task.

TABLE B-VIII (Concluded)

Case	Conf. Parameters	Pilot-Sim Mode	Z_{δ_c}	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Precision Hover, Landing Sequence and Secondary Dynamics	Pilot Comments: Overall Evaluation
XC25	RC4 $Z_{w_a}=Z_{w_s}=-0.$ T/W=[illegible]	B-FB	3.02	6	Selected in an attempt to stabilize height control.	Very difficult to perform because of attention needed to stabilize height. Couldn't perform any maneuvering task precisely because of concern about possible ground strike. Height excursions must have been up to ±60 to 75 ft. Very difficult to keep height under control and attempt to perform task.	Very difficult to perform the task with any precision because of very poor height control.	This wasn't quite as bad, could hover fairly well but had some difficulty stabilizing height. The landing sequence was next to impossible to perform. Couldn't stabilize on either 20 or 40-ft altitudes. The vertical landing also difficult, got close to the ground and then just dropped it in to prevent oscillating once more.	Definitely needs more damping in height; this is completely unacceptable.
		B-MB	3.06	6	Selected in an attempt to gain control of altitude oscillations.	Very difficult to perform. Can't do it with any precision. Must concentrate on altitude control, then this degrades maneuver performance. Altitude control no better than ±40 ft.	Had simulator emergency during the lateral quick stop because of the difficulty in controlling altitude. Can't perform any task with precision.	Couldn't hover precisely or hold hovering position while landing. Concerned mainly with height control and stabilizing it to some extent. The landing sequence was a hit and miss operation. Just had to let hovering precision deteriorate and very cautiously get altitude down to 20 ft. Had to lend control inputs a great deal.	Difficult to control height -- certainly the most objectionable feature. Extremely difficult to keep height anywhere in bounds. Needs height damping.
XC26	RC4 $Z_{w_a}=Z_{w_s}=-0.125$ T/W=[illegible]	A-FB	2.60	3	Set height control sensitivity for both altitude response and altitude stability.	Controlling altitude requires moderate pilot compensation, that is, required some anticipation to stop at desired altitude. Air taxi maneuver required moderate concentration on altitude control.	Required moderate concentration to perform it	Precision hovering required moderate pilot concentration both to offset mean wind effects on aircraft position and to control altitude. Because of the divided attention it was generally held only within ±10 ft of the desired altitude.	Most objectionable feature was the slightly low damping in altitude. Feel more damping would be required to make this a satisfactory configuration.
		B-FB	3.28	4.5	Selected for desired control response in height.	Air taxi not too difficult. Could perform it reasonably well with some precision while holding altitude within about ±5 ft. Had to pay a good deal of attention to height, more than desired.	Could perform lateral and longitudinal quick stops with reasonable precision but had to fairly constantly keep attention on height.	Precision hover not too difficult. Could hover precisely, but occasionally altitude would drift off. The landing sequence wasn't too difficult. Would like to see some more height damping, however. Difficult to stabilize and hold altitude precisely. Approached landing cautiously, but performed it OK.	Objectionable feature was primarily the lack of height damping. Would like to see a little more.
		B-MB	2.72	4.5	Height control sensitivity selected to control height oscillations.	Generally could maneuver relatively well, but think that lack of damping in height affected ability to perform maneuver. Could hold height within about ±10 ft, but altitude was in constant motion. Couldn't really stabilize on any given altitude particularly well.	No real difference in remarks compared to maneuvering.	Could hover fairly well while holding altitude without too much effort, but hovering position was degraded somewhat. Had to make fairly continuous inputs to height to keep stabilized and to keep within ±10 ft. In landing sequence could decrease altitude to about 20 ft fairly well, but every now and then would have to make an abrupt input to control hovering position.	Would like to see a little more damping in height, although this isn't critical.
XC27	RC4 $Z_{w_a}=Z_{w_s}=-0.25$ T/W=[illegible]	A-FB	3.71	3	Selected height control sensitivity for desired altitude response during takeoff and landing.	Air taxi wasn't too difficult, except that relatively large attitude changes were required to initiate and sustain velocity. Could hold heading and altitude fairly accurately with only a moderate control effort.	Most objectionable feature of quick stops was the large attitudes required to initiate the translational motion.	Was annoyed somewhat by gust disturbances during precision hover in both position and a little in attitude. This was a mildly unpleasant characteristic. Altitude control required very little activity and seemed to be fairly well damped.	Generally good configuration.
XC28	RC4 $Z_{w_a}=Z_{w_s}=-0.$[illegible] T/W=[illegible]	A-FB	3.82	3	Selected height control sensitivity to get desired response for making altitude changes.	Air taxi was relatively easy to perform because very little attention was required to control altitude. Turn-over-a-spot required pilot effort only because of the mean wind effects on position such that relatively large changes in wing tilt trim were required.	Relatively easy to control.	Precision hover was very easy from the standpoint of controlling altitude, most attention was required to offset drag effects on the airplane. Height control was very good.	Would rate it 2.0, but because of mean wind effects on the aircraft, will rate the overall configuration 3.0.

TABLE B-IX

PILOT COMMENTS FROM THE STUDIES OF HEIGHT CONTROL SYSTEM LAGS AND DELAYS AND INCREMENTAL THRUST THROUGH STORED ENERGY

Flying Qualities Results Given in Table A-X

Case	Conf. Parameters	Pilot-Rating	Z_{δ_c}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Precision Hover, Landing Sequence and Secondary Dynamics	Overall Evaluation
H11	HC1 $Z_{w_a}=Z_{w_g}=-0.125$ T/W=1.05 $\tau_v=0.3$ $\zeta_v=0.$	A-FZ	3.0	4.5		Takeoff performance quite good, but had to anticipate desired hovering altitude of 40 ft. During air taxi altitude required considerable attention, and altitude deviated more than desired.	Altitude performance was fairly good during turn maneuver, but during quick stop there was considerable variation in altitude.	Hovering performance was fairly good, but had to devote some attention to control of altitude. During landing sequence maneuver had no problem arresting sink rate but required some attention to stabilize altitude. This applied to the landing, too.	Most objectionable feature seemed to be a combination of either light damping in altitude or perhaps lag in the thrust response.
		B-FB	3.0	5.5		Altitude required considerable attention and compensation during both the maneuvering and quick stop portion of the task. Could not disregard altitude even for a moment. Had to lead inputs and make fairly continual control inputs.	Considerable pilot effort required. Performance not too good.	Could hover fairly precisely, but had to make relatively continuous altitude control inputs to hover accurately. Could perform landing sequence but had to be very careful about descending too rapidly and overshooting desired altitude. Same applied to ascending. Had to anticipate desired altitude. Couldn't land smoothly because of thrust lags.	Altitude needs more damping or lower thrust lags.
		B-KB	3.01	3	Selected to get desired height response.	No difficulty performing air taxi while holding height within fairly close tolerances, say about 25 ft. Height seemed to be relatively stable, fairly well damped and didn't change abruptly when performing the lateral maneuvers.	No problem holding height during the longitudinal quick stop; during the lateral quick stop developed some attitude angles which were large enough to introduce height errors and cause some difficulty in height control, but really nothing extreme.	No problem, could hover quite accurately and hold height very steady. In landing sequence could descend at fairly rapid rates and stop quite precisely. No oscillations evident. Could land carefully, had no worries about oscillating in height near the ground.	Can't find anything too objectionable with height, it seems to be relatively easy to control. Think the motion helped in controlling altitude.
H12	HC1 $Z_{w_a}=Z_{w_g}=-0.175$ T/W=1.05 $\tau_v=0$ $\zeta_v=0.1$	A-FB	3.0	2.5		Very good takeoff performance, had no difficulty stopping at and holding 40-ft altitude during constant altitude maneuvers. In fact very few control inputs were required while performing air taxi, quick stops and turn-over-a-spot maneuvers.		Thrust response seemed fairly good when arresting sink rate during the landing sequence maneuver and stopping at the 20-ft altitude. Thrust control was also adequate for landing.	Good altitude control.
H13	HC1 $Z_{w_a}=Z_{w_g}=-0.175$ T/W=1.05 $\tau_v=0.3$ $\zeta_v=0$	A-FZ	3.0	3		Climb out performance was good and had no problems stopping at desired altitude. Very little effort required to hold altitude while performing the air taxi, turn-over-a-spot, and quick stop maneuvers.		Hovering performance was very good and required very little effort to control altitude. There was either a slight limitation or delay in thrust when attempting to arrest sink rate, but this was no particular problem.	Only objectionable feature was the slight limit or delay in thrust when arresting sink rate.
		B-FB	3.0	3		Air taxi and quick stop maneuvers could be performed while holding altitude relatively constant. Altitude not difficult to maintain during these maneuvers. Tendency to change somewhat but not too rapidly, easily compensated.		Hover could be performed quite precisely while holding altitude within very close tolerances of about ±1 ft. The landing sequence also was not difficult to perform. Some small tendency to overshoot when descending and ascending but easy to compensate.	Would probably like to see a little more damping and a little less lag, but in general is not a bad height-control configuration.
H14	HC1 $Z_{w_a}=Z_{w_g}=-0.175$ T/W=1.05 $\tau_v=0.3$ $\zeta_v=0.1$	A-FB	3.0	3.5		Climb out was satisfactory following takeoff and had no difficulty stopping at maneuvering altitude of 40 ft. Altitude control required very little attention while performing air taxi, quick stops and turn-over-a-spot maneuvers.		Altitude control during precision hover was very good. During landing sequence did notice a little lag in thrust response in trying to arrest sink rate, so had to anticipate desired altitude. Again, during climb out thrust was adequate but noticed a slight lag in thrust response while performing the final landing.	A slightly objectionable feature seemed to be a small lag in thrust when attempting to land or arrest sink rate.
H15	HC1 $Z_{w_a}=Z_{w_g}=-0.175$ T/W=1.05 $\tau_v=0.6$ $\zeta_v=0$	A-FB	3.0	4.5		Had adequate thrust for takeoff and climb out to desired altitude. Only small amount of effort required to stabilize at desired altitude. During constant altitude maneuvers had to give some attention to controlling altitude as there was some tendency to oscillate about desired maneuvering altitude of 40 ft.	Required a little more altitude control but this was not a particular problem.	During precision hover noticed tendency to oscillate and hunt in altitude slightly, but in general performance was fairly good. During landing sequence noticed a lag in thrust when attempting to arrest sink rate, but this was only a moderate problem. Thrust response was slightly slow during landing	Most objectionable feature seemed to be a slight lag or delay in thrust response when attempting to arrest sink rate.
		B-FB	3.0	3.5		Generally could perform air taxi precisely and hold altitude fairly constant. Some small tendency for altitude to drift off but this was relatively easily corrected. Had to pay some attention to altitude but really it didn't tend to get away.	Could be performed with precision and without abrupt changes in altitude. Had to monitor altitude.	Precision hover could be performed easily and altitude presented no great problem. Could descend and ascend without too much difficulty. Did have to lead inputs, however. Has to be concerned about overshoot, especially when increasing altitude. Vertical landing could be performed quite precisely, but had to be careful in arresting sink rate.	Some thrust lag effects evident. Might like to see a little more damping, but this is not a particularly bad case.
H16	HC1 $Z_{w_a}=0.$ $Z_{w_g}=-0.35$ T/W=1.05 $\tau_v=0.6$ $\zeta_v=0$	B-FB	3.0	4		Air taxi no great difficulty. Some coupling between height and roll motion but didn't have to make particularly large or rapid inputs to correct for it. Everything pretty relaxed.	No difficulty, could hold altitude fairly well even while performing the lateral quick stop, but again there was some coupling noticeable there.	Hover no difficulty. Could hold both longitudinal and vertical position quite well. Landing sequence was a little touchy, had to be careful not to build up descent rates which were too large because of a tendency to develop some oscillations in height. Had to avoid abrupt inputs though.	Objectionable feature was slight oscillatory tendency in height, although this wasn't a problem.
H17	HC1 $Z_{w_a}=-0.25$ $Z_{w_g}=-0.25$ T/W=1.05 $\tau_v=0.6$ $\zeta_v=0$	A-FB	3.0	2.5		Good climb-out performance following takeoff. Very little altitude control was required.	These maneuvers induced some altitude error. However, control was relatively easy.	Virtually no altitude control was used during the precision hover. There was adequate thrust and damping during the landing sequence maneuver and any thrust lag was not noticeable.	Good altitude control.
N5	HC1 $Z_{w_a}=0$ $Z_{w_g}=-0.35$ T/W=1.02 $\Delta T/W=0.$ $\tau_\Delta=0$	B-HB	2.67	4	Selected to get desired height response.	Not difficult. Could maneuver accurately while holding height relatively well. Height tended to increase during the lateral maneuver, however.	Couldn't control altitude precisely during lateral quick stop.	Hover not difficult. Would prefer more thrust for arresting my rate of descent. Can't climb either. No interaction.	Moderate lags of thrust.

TABLE B-IX (Concluded)

Case	Conf. Parameters	Select. Sim. Mode	Z_{δ}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Precision Hover, Landing Sequence and Secondary Dynamics	General Comments
H02	NC1 $Z_{w_a}=0.$ $Z_{w_g}=-0.35$ $T/W=1.09$ $\Delta T/W=0.13$ $\tau_{\Delta}=0.10$	A-F3	3.0	4		Height control required attention. No abrupt changes in altitude but tended to drift off. Had to lead collective inputs and avoid building up large descent rates.	Developed height errors of 25 ft.	Hover not too difficult. Could hold altitude precisely. Moderately difficult to arrest my descent at 20 ft and stabilize altitude there. Lack of available thrust. Could land safely, however.	Needs more installed thrust-to-weight ratio and possibly more damping.
H03	NC2 $Z_{w_a}=0.$ $Z_{w_g}=-0.35$ $T/W=1.02$ $\Delta T/W=0.13$ $\tau_{\Delta}=0.2$	A-F3	3.0	3		Height control required some attention but only low-frequency corrections needed. Didn't have to lead inputs much.	Height control not difficult.	Could hover precisely with only small variations in altitude. Relatively easy to perform landing sequence. Could build up appreciable altitude rates, sustain them, and arrest height changes quickly.	
		A-HD	2.65	3.5	Selected to get desired rate of height change.	No problem either laterally or longitudinally. Could maneuver and stop precisely. No difficulty holding altitude quite precisely.	No problem even in lateral quick stops. Could stop abruptly and hold altitude quite precisely.	Hover no problem. Generally could handle landing sequence fairly well. A little concerned with ability to stop rate of descent. At times overshot altitude a little, so had to descend with some care. Think thrust is adequate.	Objectionable features - A slight objection to lack of thrust that was evident when trying to stop fairly high descent rates.
H04	NC1 $Z_{w_a}=0.$ $Z_{w_g}=-0.35$ $T/W=1.02$ $\Delta T/W=0.20$ $\tau_{\Delta}=0.10$	A-F3	3.0	3.5		Altitude required attention when maneuvering. However, generally could control it fairly well. Some tendency to creep off and increase altitude but it happened relatively slowly. Could build up fairly significant rates and arrest them without too much difficulty.	Required some attention, but could control altitude fairly well.	Hover no problem. Could perform this precisely and hold altitude quite accurately. The landing sequence also not too difficult. Could go down to 20 ft at a relatively rapid rate and arrest altitude without too much difficulty. Did have some problems stabilizing it but nothing too significant.	Fairly good case.
		A-HD	2.07	3	Selected to get desired response in height and desired rate of change of altitude for a comfortable control input	Generally no problems with air taxi. Could maneuver precisely and hold altitude accurately.	Performed quick stops precisely and had no problem holding height.	Hover was not difficult. Some lack of thrust when arresting descent. Concerned with building up too large a descent rate, however, seemed to be able to ascend as rapidly as desired. Seemed to have adequate thrust available.	Objectionable feature was the slight lack of thrust when descending. A little concerned with inability to arrest descent rates, but with care can keep them well under control.
H05	NC2 $Z_{w_a}=0.$ $Z_{w_g}=-0.35$ $T/W=1.02$ $\Delta T/W=0.25$ $\tau_{\Delta}=0.05$	A-F3	3.0	3.5		During maneuver had to watch altitude reasonably closely. Tended to increase slightly, but didn't seem to be difficult to control and it was reasonably predictable. Don't recall having to lead inputs too greatly.	No problem with altitude control.	Could hover precisely and hold altitude closely. Landing sequence was not difficult to perform. Could hover precisely and descend to the 20-ft altitude with no difficulty. Didn't seem to have any real problems arresting descent rates	Couldn't let descent rates build up too large but for normal descent could arrest altitude precisely.
		A-HD	2.07	4	Selected to get desired altitude response.	Air taxi not difficult. Height control didn't affect ability to control longitudinal or lateral motion while maneuvering. Had a little difficulty holding altitude. Would drift up and down about ±5 ft or so	Could stop quickly and precisely, at least longitudinally, without having altitude change too much. Did lose some altitude during the lateral quick stop. May have lacked a little thrust to recover altitude.	Hover not difficult. Had to be a little careful about rate of descent. Couldn't descend rapidly and stop abruptly. Had to slow down relatively easily.	Objectionable feature - Slight lack of thrust during descent and when trying to recover height during lateral quick stops.

TABLE B-X (Continued)

Case	Conf. Parameters	Pilot-Sim. Mode	S_{δ_r}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
D6	BC1 $X_v=-0.5$ X_{δ_m}=UL $\tau_\psi=0.$ $\zeta_\psi=0.1$	B-FB	0.270	3.5	Selected to get desired heading rate of change.	No problem. Relatively easy to hold heading. Had to make some corrective heading inputs when maneuvering laterally but heading was well damped. Didn't develop any heading oscillations.	No difficulty in performing these tasks. Some corrective inputs required when maneuvering laterally, but could make a good sharp lateral quick stop.	Relatively easy to set up and hold a heading rate and stop precisely at any heading. Wing tilt control was used a small extent.	Hover not difficult. No interaction between heading dynamics and control of other axes.	No objectionable features, this is a good case. Heading is well damped, no evident lags.
D7	BC1 $X_v=-0.5$ X_{δ_m}=UL $\tau_\psi=0.3$ $\zeta_\psi=0.$	A-FB	0.273	4.5	Set to maintain directional control in presence of gusts and lags in the directional control.	Performance fairly good, but had some difficulty controlling heading during lateral maneuvers due to gust effects and directional coupling to lateral speed.	Only difficulty was associated with heading control during changes in lateral velocity.	Heading was very responsive to pedals but required anticipation to stop at desired heading due to lags in directional control. Used a small amount of wing tilt control.	Hover performance good but did require attention on direction.	Most objectionable features were related to slightly low damping in direction, gust effects on direction and lag in response to directional control inputs.
		B-FB	0.181	5	Selected to control heading oscillations, especially when trying to hold heading precisely during maneuver or hover.	Ability to maneuver was affected by difficulty in holding heading. Heading tended to oscillate ±5 deg almost constantly. Heading was never really stable. Lateral maneuver especially difficult.	Could perform these tasks, but heading required a fair amount of attention. Difficult to control height because of attention required for heading.	Could turn over the spot fairly well and stop fairly precisely. Didn't seem to get into heading oscillations. Wing tilt control used to some extent.	Had some difficulty hovering because of heading control. Vertical landing could be performed alright. Heading did affect ability to control in other axes.	Objectionable features - the lack of damping in heading and/or the lags.
		B-MB	0.259	4.5	Selected to get heading rate response and also to control heading oscillations.	In lateral maneuver had a tendency to develop heading errors and oscillations. Oscillations generally were low level and not too difficult to control, but annoying.	In lateral quick stops had to watch heading fairly closely and make corrections which could develop into oscillations.	If performed slowly could turn and stop precisely, but if heading rates built up and tried to arrest heading abruptly, tended to develop significant heading oscillations. Difficult to damp.	Hover and landing no problem. Think heading affected ability to control roll and lateral motion.	Objectionable features - Don't like the oscillatory characteristics in heading. The lag is apparently present.
D8	BC1 $X_v=-0.5$ X_{δ_m}=UL $\tau_\psi=0.3$ $\zeta_\psi=0.1$	B-FB	0.260	5.5	Selected to get desired turn rate for heading control.	Found it difficult to stabilize heading when maneuvering laterally. Built up fairly significant oscillations in heading (about ±10 to ±15 deg) that affected ability to perform lateral maneuver.	Only lateral quick stop was difficult. Ability to perform quick stop affected by the heading control difficulty.	Could develop and hold turn rate fairly well, but had difficulty stopping on desired heading and stabilizing it. Wing tilt control used to some small extent.	No problem with hover. Had to be light on the controls to keep heading oscillations relatively small. Landing no difficulty. Heading control definitely affected ability to perform lateral maneuvers.	Heading control objectionable, the lags are simply too large. Tend to develop oscillations.
		B-MB	0.226	5	Selected to control heading oscillations.	Developed heading oscillations when maneuvering both laterally and longitudinally. Somewhat difficult to control heading. Tends to stray away, very oscillatory.	Especially during lateral quick stops heading was oscillatory and required significant amount of attention.	Had to be careful not to slide by desired heading. Very easy to do with this case.	hover and vertical landing not difficult. Heading control affected ability to control pitch, roll and to some extent height. Took attention away from these other axes.	Objectionable features - lack of damping and lag in heading control.
		A-FB	0.235	4	Set for desired response while making heading changes.	Relatively easy except lateral maneuver required attention to maintain heading. Performance relatively good however.	Required a little more attention on heading.	Performance fairly good although couldn't maintain a constant turn rate very accurately. Required a little anticipation to stop at desired heading and some difficulty stabilizing it.	Precision hover and landing performance good and required very little effort.	Only objectionable feature was that directional damping was slightly low.
D9	BC1 $X_v=-0.5$ X_{δ_m}=UL $\tau_\psi=0.6$ $\zeta_\psi=0.$	B-FB	0.232	6	Selected to get desired turn rate for an acceptable pedal input and also in an attempt to hold control heading oscillations.	Performance affected by lack of damping and lags in heading. Tended to develop fairly constant heading oscillations during maneuver. This was more pronounced while maneuvering laterally.	Ability to perform this subtask also affected by the lack of damping in heading.	Could turn fairly well and control turn rate without much difficulty, but it was tough to hold a heading. Wing tilt used a little.	While hovering was oscillating in heading. Could hover fairly well, but at times hover position was affected by attention being diverted to heading. Had to watch heading while landing. Lack of damping and lag in heading affected ability to control roll, pitch and height.	Needs some more damping in heading or reduction in lags. Almost impossible to damp out heading oscillations; ability to control other axes is affected.
D10	BC1 $X_v=-0.5$ X_{δ_m}=UL $\tau_\psi=0.6$ $\zeta_\psi=0.1$	B-FB	0.248	6	Selected to get turn rate desired for a given pedal input.	Could perform the longitudinal maneuver relatively well, but lateral maneuver was more difficult. Had to be very careful to avoid exciting heading oscillations. Could not control heading too tightly. Very definite tendency to build up PIO's in heading.	Difficult to perform. Had to be careful about heading control.	Not too difficult, but it was tough to stop on a given angle precisely. Tendency to oscillate to fairly large heading angles.	Could perform hover and landing fairly well, but heading did tend to wander. Very definite lack of damping, the lags in heading affect ability to control pitch and especially roll.	The PIO tendency in heading due to lags and delays are objectionable. All cases with large lags are somewhat unusual in that if control inputs kept small they aren't that bad, but one can develop large oscillations so quickly that they must be regarded as undesirable.
D11	BC1 $X_v=-1.0$ X_{δ_m}=UL $\tau_\psi=0.1$ $\zeta_\psi=0.$	B-FB	0.306	3	Selected to get the desired turn rate.	Could perform this maneuver quite well, heading control no problem. Noticed some very slight oscillations in heading, but not difficult to control.	Noticed some slight oscillatory tendency in heading, very, very slight, easily correctable.	Could turn precisely, select turn rate desired without too much trouble. Wing tilt control used a little to correct the effects of mean wind.	No problems. Some slight tendency to oscillate back and forth in heading but didn't affect ability to hover or land precisely.	No real objectionable features. Slight tendency for heading to oscillate, but not difficult to control.

TABLE B-X (Continued)

Case	Ref. Parameters	Pilot-Sim. Mode	τ_{ψ_r}	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Turn-Over-a-Spot	Pilot Comments: Precision Hover, Vertical Landing, Secondary Dynamics	Pilot Comments: Overall Evaluation
D12	RC1 $Y_v=-1.0$ N_{δ_r}=UL $\tau_\psi=0.$ $\zeta_\psi=0.1$	B-FB	0.294	2	Selected to get desired turn rate response to pedal inputs.	Could perform both lateral and longitudinal maneuvers precisely while paying very little attention to heading control. Heading quite stable, no tendency towards oscillations.	No difficulty.	Could turn quite precisely, stop abruptly and remain there without oscillation. Heading control no problem.	Could hover quite accurately, hold position well without having to worry about heading.	No objectionable features. All axes well damped. Comfortable aircraft to fly.
D13	RC1 $Y_v=-1.0$ N_{δ_r}=UL $\tau_\psi=0.3$ $\zeta_\psi=0.$	A-FB	0.341	3	Set to get desired heading response.	During air taxi heading response was relatively easy and gust effects and coupling to lateral velocity were rather minimal.	Required some attention to control heading due to lateral velocity coupling during the lateral quick stop maneuvers.	Easy to maintain a constant turn rate and to stop at desired heading. May have noticed a very slight lag in directional response but because of the relatively slow control in direction this was of no particular problem.	Hover and landing no problem.	Good directional control characteristics.
		B-FB	0.313	4	Selected to get desired turn rate response to pedal inputs.	Could perform task fairly well. Annoyed at times by the slight oscillation that built up in heading, say ±5 deg. Seemed to excite it more often when maneuvering laterally, required some attention to damp it.	Could perform the quick stops rather well but at times had some problems with the heading oscillations.	Could perform task quite well. Could turn at desired rate, stop precisely, and hold heading without too much trouble. Remained over the spot fairly well.	Could hover quite accurately and land without too much trouble. Some interaction between the heading control requirements and ability to control other axes.	Slight oscillation that built up in heading periodically was probably the only objectionable feature in heading.
		A-MB	0.275	3.5	Selected to get desired turn rates.	No problem either laterally or longitudinally. Laterally did develop some small heading motion but no real oscillations and easily controlled.	No problem longitudinally. Laterally had to watch heading a little but it was quite easy to stabilize.	No real problem stabilizing heading after the turn.	Precision hover and vertical landing not difficult. Heading control did not affect other axes.	No significant objectionable features. Heading a little oscillatory.
D14	RC1 $Y_v=-1.0$ ζ_n=UL $\tau_\psi=0.3$ $\zeta_\psi=0.1$	A-FB	0.253	3	Set for desired heading response to pedal inputs.	Relatively effortless but had to give a little attention to heading control during lateral maneuvers. Gust effects on direction were minimal.	Task posed no particular problems.	Turn rate control quite good and could stop at desired heading with relatively little anticipation. Used relatively little wing tilt control.	Performance was good and required very little effort.	Mildly annoying characteristics here were slight gust effects and control lags in heading, however, only slightly noticeable and little attention required.
		B-FB	0.305	4.5	Selected to get desired rate of heading change.	Task not difficult longitudinally; laterally had some difficulty holding heading and developed heading oscillations that at times affected ability control lateral displacement.	Lateral quick stops required attention in heading; feel performance degraded by lags in heading control.	Could hold and develop a turn rate fairly well but tended to develop some oscillations after attempting to arrest the heading. Wing tilt control was used a little.	Hover and landing presented no problems. Heading dynamics did affect ability to control laterally somewhat.	Objectionable feature was the lag in heading, although it could have been worse.
		B-MB	0.270	3.5	Selected to get desired turn rates.	Noticed some slight heading oscillations for both lateral and longitudinal maneuver, but in general could control them while paying only moderate attention.	Heading oscillations were evident for both lateral and longitudinal quick stops, but it was not particularly difficult to control. Possibly ability to perform the task was degraded slightly due to attention devoted to heading	Not too difficult, some tendency to slide by desired heading and then develop oscillations when attempting to recover.	Precision hover and vertical landing not difficult. Heading dynamics did affect ability to control pitch and roll to some small extent.	Would like more damping or less lag in heading.
D15	RC1 $Y_v=-1.0$ N_{δ_r}=UL $\tau_\psi=0.6$ $\zeta_\psi=0.$	A-FB	0.271	4	Set to get desired heading response.	Had to give some attention to directional control, especially during lateral maneuver due to some gust effects and due to directional coupling to lateral velocity.	During the lateral translation had to give some attention to heading control.	Turn rate control wasn't quite as good as desired and it required a little anticipation to stop at desired heading. Lags were not particularly noticeable.	Hover performance was good only direction required a small amount of attention.	Most objectionable feature seemed to be a slight deficiency in damping in direction needed to suppress gust disturbances and minimize disturbances due to lateral maneuvering velocity.
		A-FB	0.237	5	Selected to control somewhat unstable heading when attempting to hold it closely, used reduced value so that wouldn't excite motion.	Could be performed, but heading affected precision, this was especially true when maneuvering laterally. Couldn't keep from exciting heading oscillations which were about ±10 deg.	Too much attention necessary for heading control to keep it from oscillating.	Could perform task alright. Turn was performed relatively slowly but quite accurately, wing tilt control was used.	Could hover fairly well, didn't have too much difficulty holding heading in hover and landing. Heading dynamics affected ability to control during lateral maneuvers and quick stops.	Objectionable features were lack of heading damping and/or the lags in heading.
		B-MB	0.258	5	Selected to get turn rate and also to help in controlling heading oscillations.	During lateral maneuvers had to watch heading but didn't seem to get into any large oscillations. Some annoyance since had to pay more attention to it than desired.	Had to watch heading in lateral quick stop. Possible to get into fairly substantial oscillations in heading.	Approached turns very carefully. Didn't want to develop large oscillations which could happen if rapid turn attempted.	Precision hover and vertical landing no problem. Heading dynamics affected ability to control somewhat.	The lag in heading control which led to heading oscillations during the turn and lateral maneuvers was objectionable.
D16	RC1 $Y_v=-1.0$ N_{δ_r}=UL $\tau_\psi=0.6$ $\zeta_\psi=0.1$	A-FB	0.308	4	Selected to stabilize heading control.	Had some trouble during lateral maneuvers holding heading and at times almost had a PIO-type situation in controlling heading. Heading was disturbed to some extent by gusts and by the coupling with lateral velocity. Had some difficulty commanding and holding heading without overshooting the desired heading.	Had heading control problems similar to those in air taxi.	Wasn't too difficult, but it required some anticipation to stop at desired heading. Very little wing tilt control used.	Hover wasn't too bad, although had to provide some concentration on heading to hold within ±5 deg.	Biggest problem was commanding and holding at desired heading. Seemed to be some lag in the response and at times almost got into a PIO-type situation.

TABLE B-X (Continued)

Case	Conf Parameters	Pilot-Sim. Mode	N_{δ_r}	PR	Pilot Comments: Selection of Control Sensitivities	Maneuvering	Quick Stops	Turn-Over-a-Spot	Precision Hover, Vertical Landing, Secondary Dynamics	Overall Evaluation
216	RC1 $X_v=-1.0$ $N_{\delta_p}=$[illegible] $T_\psi=0.6$ $\zeta_\psi=0.1$	A-7B	0.300	5.5	Selected to get desired turn rate response.	Had some difficulty stabilizing heading. Heading would tend to oscillate through fairly large angular swings, ±10 to 15 deg, during lateral maneuvers. Had to keep pedal inputs as small as possible.	Lateral quick stops did present somewhat of a problem, had to watch heading closely and keep correcting it as it tended to oscillate some.	Could turn over the spot fairly accurately and stop fairly well. Kind of difficult to hold turn rate; rates would tend to build up and then taper off.	Precision hover and vertical landing presented no problem. Large lag in heading affected ability to control laterally.	The oscillatory characteristic in heading and the lag in response are objectionable.
		B-KE	0.264	4.5	Selected to get desired turn rates.	No real problem. Could perform both laterally and longitudinally without difficulty. Had to watch heading a little during the lateral maneuvers and correct for some heading motion.	Again no problem. Had to correct for heading changes during lateral maneuvers but not difficult.	Could turn precisely and stop fairly quickly. Every now and then developed a small oscillation but not difficult.	Precision hover and vertical landing no problem. Heading control didn't affect ability to control other axes.	Objectionable features - small oscillatory tendency in heading.
217	RC1 $X_v=-0.5$ $N_{\delta_p}=0.10$ $T_\psi=0.$ $\zeta_\psi=0.$	A-7B	0.23[illegible]	6	Selected to get desired turn rate for a given pedal input.	Laterally ran into difficulties. Didn't have enough control power to counteract the effects of N_v when maneuvering laterally; this once led to oscillations. Had to be very careful to keep heading as close to zero as possible because if a yaw error developed there was no way to get heading back during maneuver.	Same situation during the lateral quick stops and once got into some moderate oscillations during the lateral quick stop.	Not difficult. At a low turn rate can stop precisely and hold heading relatively well. Wing tilt control used to a small extent.	No problem with heading during hover or landing. The lack of control power in heading coupled with the low damping affected ability to control roll and lateral position.	The lack of directional control power and damping is the primary objectionable feature.
218	RC1 $X_v=-0.5$ $N_{\delta_p}=0.13$ $T_\psi=0.$ $\zeta_\psi=0.$	A-7B	0.238	4	Selected to get desired turn rate response.	Not difficult. Laterally somewhat more difficult as could introduce some relatively small heading oscillations. Bothered a little when maneuvering laterally by the lack of control power and damping, but in general could perform these tasks without much difficulty.	Could perform the lateral quick stop fairly precisely and make a large bank angle change to stop abruptly, but had to watch heading somewhat.	No difficulty except had to avoid building up turn rates which were too large, otherwise would overshoot desired heading.	Hover and vertical landing not difficult. Some minor interaction between heading dynamics and roll control, lateral position control.	Control power is just marginal, would like to see a little more damping, although the case is not too difficult.
219	RC1 $X_v=-0.5$ $N_{\delta_p}=0.16$ $T_\psi=0.$ $\zeta_\psi=0.$	A-7B	0.235	3.5	Selected to get desired turn rate.	Really no great difficulty in performing air taxi. Some oscillatory characteristics in heading during lateral maneuvers, but easily controlled.	Could perform reasonably precisely, but again some oscillatory characteristics in heading when trying to perform the lateral quick stop.	Generally not difficult, but must avoid building up high turn rates so as to not overshoot heading and go into oscillations.	Hover and vertical landing no problem. Lack of damping in heading had minor effect on ability to control laterally.	Would like to see a little more damping in heading, but the case isn't too bad.
220	RC1 $X_v=-1.0$ $N_{\delta_p}=0.10$ $T_\psi=0.$ $\zeta_\psi=0.$	A-7B	0.700	5	Set for desired directional response.	Performance fairly good and noticed no deficiencies in control power or damping.	Noticed a little lack of directional control power when maneuvering laterally while trying to hold heading.	Could not turn at a very high rate due to inadequate directional control power. Practically slowed to a stop when 90 deg to the wind. Had to anticipate desired heading because of insufficient control power.	Precision hover performance was good and there were no deficiencies.	Most objectionable feature was the insufficient directional control power. Could perform the task but it required some additional compensation and workload.
		B-7B	0.306	5.5	Selected to get desired turn rate response.	Ran out of control power during lateral maneuvers, couldn't counteract the effect of N_v. In lateral maneuver to left the nose rotated to the left and couldn't bring it back.	No problem longitudinally but developed some heading oscillations during the lateral quick stop because of deficiency in control power.	Could perform this relatively well, but could not turn particularly fast. Had to be careful to turn slowly to avoid overshooting desired heading.	No problem with hover and landing. The lack of heading control power did effect ability to control laterally during lateral quick stop and during the lateral maneuvers.	The lack of directional control power was objectionable, really need some more to perform the tasks adequately.
		B-KE	0.273	7	Selected to get desired turn rates.	Longitudinal maneuver no problem. In lateral maneuvers tended to run out of yaw control power when large turn rates built up. Affected ability to hold heading.	Generally not difficult, some tendency to develop larger than desirable heading angles when maneuvering laterally.	Difficult to control heading. Could arrest turn rate, but when at 90 deg to the mean wind it was difficult to stabilize heading. Need more control power.	These tasks not difficult. Lack of directional control power definitely affected ability to control pitch and roll.	Lack of control power in heading was very objectionable.
221	RC1 $X_v=-1.3$ $N_{\delta_p}=0.13$ $T_\psi=0.$ $\zeta_\psi=0.$	A-7B	0.236	3	Set for desired directional response.	Directional damping was good and had no problem performing the air taxi maneuver or holding heading during that maneuver.	Quick stop maneuvers no problem.	Had good rate control, however, when 90 deg to the mean wind noticed a lack of control power as relatively slow turn rate. Didn't degrade performance and only slightly noticeable.	Hover performance good and directional control quite adequate.	Only slightly objectionable feature was a noticeable reduction in directional control power when 90 deg to the mean wind.
		B-7B	0.306	3.5	Selected to get turn rates that were desirable.	Could perform without difficulty. Had to be somewhat careful to avoid developing large heading rates. As long as directional inputs were moderate, could control quite well, but noticed the lack of control power every now and then when heading rates got a little large.	Could perform these tasks quite well, both lateral and longitudinal.	Not difficult, but had to avoid developing turn rates which were too large. If turn too rapid would overshoot and it would be difficult to get heading under control again. With small turn rates no problem.	Hover and landing no problem. No noticeable interaction of heading with roll and pitch.	Just a slight lack of yaw control power. Would like to see a little more in case of large heading rates or an emergency.
		B-KE	0.2[illegible]	2.5	Selected to get desired turn rates.	No problem with lateral or longitudinal maneuvers. No apparent absence of control power.	Could perform these maneuvers fairly precisely. No loss of control power evident. Had to be concerned to a limited extent with heading, but it was well damped.	No difficulty, could turn rapidly, stop precisely. Again no evidence of a lack of control power even when 90 deg to the mean wind.	No difficulty with hover and landing. No interaction of heading with other axes.	No real objectionable features. Good characteristics in heading.

TABLE B-X (Concluded)

Case	Config. Parameters	Pilot Sim. Mode	ζ_r	PR	Pilot Comments: Selection of Control Sensitivities	Pilot Comments: Maneuvering	Pilot Comments: Quick Stops	Pilot Comments: Turn-Over-a-Spot	Pilot Comments: Precision Hover, Vertical Landing, Secondary Dynamics	Pilot Comments: Overall Evaluation
282	NCA N_r=-1.0 N_{δ_r}=0.16 Y_p=0. A_p=0.	A-FR	0.297	3	Set for desired response to pedal inputs.	Good control during air taxi, only slight attention required to control heading during the lateral maneuver. Good damping and adequate control power about all axes	No particular problems, but lateral quick stop required some attention.	Turn rate could be held quite accurately and there was no problem in stopping at desired heading. Adequate directional control power to control mean wind effects.	Hover performance was very good and required very little attention.	Noticed no deficiency in control power and could perform the tasks quite well.
		B-FB	0.306	2	Selected for desired heading response for turns.	No problem laterally or longitudinally. Could perform these tasks precisely and didn't have to compensate much for heading changes. Heading quite stable, not affected much at all during lateral maneuvers. Plenty of control power.	Same type of comments as for maneuvering.	No problem, could turn precisely and rapidly and still stop accurately. Wing tilt control used to a small extent.	Not at all difficult to hover and land, could perform these tasks precisely and they weren't at all affected by the heading dynamics.	No objectionable features. Good case.
		L-KG	0.294	2.5	Selected to get desired turn rate response.	Lateral and longitudinal maneuvers no problem. Well damped. Fine heading control, no indication of a lack of control power.	No problem. Could perform the lateral quick stop precisely, small compensatory inputs in heading.	Also no problem, can turn rapidly, stop precisely.	Precision hover and vertical landing not difficult. No interaction among the dynamics.	No objectionable features. Good case.

APPENDIX C

SUMMARY OF CONTROL-POWER-USAGE DATA

Control-power-usage data, which generally consist of the control power levels exceeded five percent of the time, are listed in this Appendix. For some of the studies concerned with control-power limits, the percent times that the control power command exceeded these limits are also presented. Data are shown in this Appendix only for selected test cases, i.e., the exceedance computations were not performed on all the cases considered in the UARL program.

The control-power-usage data tables also generally parallel the tables in Appendices A and B. Control-moment data from the longitudinal and lateral control studies are summarized in Tables C-I through C-VI as follows: C-I, turbulence effects; C-II, control lags and delays; C-III, control-moment limits; C-IV, inter-axis motion coupling; C-V, independent thrust-vector control; and C-VI, rate-command/attitude-hold control. Thrust-usage data from the height control study are presented in Table C-VII. Results from the studies of the interactive effects of height velocity damping and thrust-to-weight ratio and thrust lags and delays are shown there. Control-moment-usage data from the directional control studies are contained in the last table, C-VIII.

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TABLE C-I

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT OF THE TIME FROM THE STUDY OF TURBULENCE INTENSITY

Vertical and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

Case[1] - Basic Conf.	Stability Derivatives[2]				Turbulence, $\sigma_{u_g} = \sigma_{v_g}$	Subtask[3]	Fixed Base								Moving Base			
							Pilot A				Pilot B				Pilot B			
	M_{u_g}	X_u	M_q	M_θ			M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
						XM	0.33		0.38		0.35		0.45		0.35		0.39	
T1						YM		0.22	0.38			0.40	0.58			0.27	0.43	
-	0.33	-0.05	-1.7	-4.2	3.4	XQS	0.34		0.39		0.39		0.50		0.30		0.42	
BC1						YQS		0.44	0.54			0.58	0.70			0.32	0.50	
						TU	0.28	0.30	0.45	0.07	0.33	0.48	0.64	0.05	0.28	0.28	0.42	0.08
						HOV	0.26	0.22	0.43		0.31	0.35	0.57		0.26	0.23	0.47	
						XM					0.40		0.52					
T2						YM						0.39	0.57					
-	0.33	-0.05	-1.7	-4.2	5.8	XQS					0.48		0.58					
BC1						YQS						0.62	0.78					
						TU					0.37	0.44	0.63	0.15				
						HOV					0.79	0.30	1.01					
						XM	0.48		0.78		0.41		0.70		0.43		0.63	
T3						YM		0.46	0.66			0.57	0.80			0.34	0.61	
-	0.33	-0.05	-1.7	-4.2	8.2	XQS	0.44		0.62		0.56		0.87		0.44		0.60	
BC1						YQS		0.73	0.85			0.48	0.81			0.38	0.65	
						TU	0.37	0.43	0.69	0.08	0.46	0.51	0.71	0.09	0.37	0.25	0.52	0.07
						HOV	0.43	0.30	0.60		1.38	0.38	1.56		0.38	0.30	0.60	
						XM	0.40		0.47		0.39		0.50		0.29		0.43	
T4						YM		0.39	0.57			0.39	0.58			0.29	0.45	
-	0.33	-0.20	-1.7	-4.2	3.4	XQS	0.53		0.57		0.45		0.59		0.37		0.40	
BC5						YQS		0.63	0.72			0.54	0.73			0.34	0.53	
						TU	0.44	0.26	0.55	0.11	0.35	0.38	0.56	0.11	0.29	0.20	0.40	0.07
						HOV	0.35	0.39	0.40		0.44	0.39	0.65		0.40	0.28	0.53	
						XM	0.88		1.15		0.85		1.05		0.97		1.17	
T5						YM		0.79	1.32			0.50	1.01			0.56	1.14	
-	1.0	-0.20	-3.0	-1.7	3.4	XQS	0.69		1.03		0.89		1.07		0.90		1.07	
BC4						YQS		0.87	1.58			0.49	1.03			0.48	1.15	
						TU	0.73	0.65	1.02	0.10	0.71	0.73	1.12	0.13	0.76	0.48	0.94	0.05
						HOV	0.83	0.44	1.16		0.77	0.35	0.90		0.83	0.42	1.15	

TABLE C-I (Concluded)

Case[1] - Basic Conf.	Stability Derivatives[2] M_{ug}	X_u	M_q	M_θ	Turbulence, $\sigma_{u_g}=\sigma_{v_g}$	Subtask[3]	Fixed Base, Pilot A: M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	Fixed Base, Pilot B: M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	Moving Base, Pilot B: M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
						XM	1.09		1.46		0.89		1.18		1.07		1.24	
T6						YM		0.75	1.37			0.64	1.25			0.74	1.36	
-	1.0	-0.05	-1.1	-2.5	3.4	XQS	0.95		1.18		1.0		1.28		1.09		1.29	
BC2						YQS		1.14	1.47			0.68	1.22			0.74	1.22	
						TU	0.73	0.74	1.20	0.12	0.91	0.94	1.40	0.11	1.28	0.79	1.75	0.05
						HOV	0.87	0.54	1.29		0.98	0.45	1.01		0.98	0.43	1.18	
						XM	0.87		1.05		0.92		1.30		0.90		1.07	
T13						YM		0.31	1.31			0.65	1.30			0.58	1.06	
-	1.0	-0.20	-1.1	-2.5	3.4	XQS	0.93		1.05		0.99		1.32		0.87		1.01	
BC6						YQS		1.37	1.90			0.80	1.39			0.62	1.11	
						TU	0.81	0.68	1.08	0.09	0.95	0.75	1.32	0.13	0.89	0.52	1.14	0.13
						HOV	0.65	0.58	1.30		0.77	0.37	0.98		0.79	0.42	1.07	
						XM					1.13		1.60		1.09		1.50	
T14						YM						0.92	1.64			0.83		
-	1.0	-0.20	-1.1	-2.5	5.8	XQS					1.31				1.13		1.30	
BC6						YQS						0.86				0.72	1.39	
						TU					1.00	1.13	1.63	0.13	0.90	0.70	1.27	0.05
						HOV					1.31	0.97			1.03	0.54	1.24	
						XM	1.17		1.90		1.08		1.85					
T15						YM		1.21	1.87			0.93	1.58					
-	1.0	-0.20	-1.1	-2.5	8.2	XQS	1.57		2.20		1.18		1.70					
BC6						YQS		1.51	2.00			1.29						
						TU	1.53	1.07	1.90	0.18	1.09	1.21		0.12				
						HOV	1.21	1.14	1.90		1.19	1.04	1.87					
						XM	0.97		1.28		0.98		1.18		1.14		1.31	
T16						YM		0.82	1.35			0.97	1.41			0.55	1.33	
-	1.0	-0.05	-2.0	0	3.4	XQS	1.02		1.27		1.03		1.21		1.24		1.50	
BC3						YQS		1.32	1.80			0.80	1.24			0.54	1.16	
						TU	0.91	0.80	1.35	0.11	1.35	0.83	1.60	0.13	0.98	0.65	1.16	0.01
						HOV	0.81	0.60	1.24		0.88	0.60	1.29		0.87	0.35	1.04	

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.

4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function $(|M_c| + |L_c|)$.

TABLE C-II (Concluded)

Case[1] - Basic Conf.	Stability Derivatives[2]				Lag	Delay	Sub-Task[3]	Fixed Base								Moving Base			
								Pilot A				Pilot B				Pilot B			
	M_{ug}	X_u	M_q	M_θ	τ_e,τ_a	d_e,d_a		M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
							XM					0.81		1.13					
LL5							YM						0.59	1.28					
-	1.0	-0.20	-1.1	-2.5	0.60	0	XQS					0.78		1.04					
BC6							YQS						0.68	1.29					
							TU					0.96	0.72	1.37	0.08				
							HOV					0.94	0.58	1.18					
							XM					0.34		0.48					
LL 23							YM						0.29	0.47					
-	0.33	-0.20	-1.7	-4.2	0	0.2	XQS					0.35		0.42					
BC1							YQS						0.53	0.67					
							TU					0.29	0.34	0.52	0.12				
							HOV					0.31	0.35	0.57					
							XM					0.33		0.41					
LL-24							YM						0.25	0.48					
-	0.33	-0.20	-1.7	-4.2	0.3	0.1	XQS					0.33		0.39					
BC1							YQS						0.37	0.56					
							TU					0.25	0.24	0.39	0.11				
							HOV					0.29	0.19	0.41					
							XM					0.59		1.24					
LL-25							YM						1.10	1.29					
-	0.33	-0.20	-1.7	-4.2	0.3,0	0.1,0	XQS					0.85		1.33					
BC1							YQS						1.14	1.34					
							TU					0.68			0.09				
							HOV					0.55	0.95	1.27					

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.

4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function $(|M_c| + |L_c|)$.

TABLE C-III

PERCENT TIME PITCH, ROLL AND YAW CONTROL-MOMENT COMMANDS EXCEEDED INSTALLED MOMENT LIMITS

Vertical and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

Case[1] - Basic Conf.	Stability Derivatives[2]				Maximum Control Moment Available			Lag	Delay	Sub-Task[3]	Fixed Base								Moving Base			
											Pilot A				Pilot B				Pilot B			
	$M_{u\delta}$	X_u	M_q	M_θ	M_{c_m}	L_{c_m}	N_{c_m}	τ_e,τ_a	d_e,d_a		P_{ML}	P_{LL}	P_{SL}	P_{NL}	P_{ML}	P_{LL}	P_{SL}	P_{NL}	P_{ML}	P_{LL}	P_{SL}	P_{NL}
LM1 - BC1	0.33	-0.05	-1.7	-4.2	0.360	0.415	0.120	0	0	XM					7.6		1.6		14.9		0	
										YM						4.4	0.4			0	0	
										XQS					21.4		13.0		9.7		0	
										YQS						8.6	4.0			0	0	
										TU					1.2	2.3	0	3.1	2.0	1.3	0	2.8
										HOV					3.0	1.1	0.2		0.8	0.2	0	
LM2 - BC1	0.33	-0.05	-1.7	-4.2	0.396	0.457	0.132	0	0	XM	0		0		0.9		0		0		0	
										YM		0	0			0.5	0			0	0	
										XQS	0		0		8.1		0		0.7		0	
										YQS		0	0			4.3	0			0.2	0	
										TU	0	0	0	0	0.9	1.5	0	0	0.3	0.4	0	0
										HOV	0	0	0		2.0	0.3	0		0.2	0	0	
LM3 - BC1	0.33	-0.05	-1.7	-4.2	0.432	0.498	0.144	0	0	XM					2.5		0					
										YM						0.1	0					
										XQS					2.0		0					
										YQS						2.8	0					
										TU					0	1.6	0	0				
										HOV					1.9	0.3	0					
LM5 - BC5	0.33	-0.20	-1.7	-4.2	0.300	0.280	0.120	0	0	XM									1.02		0	
										YM										1.6	0	
										XQS									0		0	
										YQS										2.0	0	
										TU									0.6	1.7	0	0
										HOV									0	0.3	0	
LM6 - BC5	0.33	-0.20	-1.7	-4.2	0.350	0.360	0.150	0	0	XM	0		0									
										YM		3.7	0									
										XQS	3.5		0									
										YQS		18.3	0									
										TU	1.6	2.2	0	0								
										HOV	0	1.9	0									
LM9 - BC4	1.0	-0.20	-3.0	-1.7	0.902	0.666	0.193	0	0	XM					1.8		0					
										YM						0	0					
										XQS					2.4		0					
										YQS						0.1	0					
										TU					0.5	6.1	0	0				
										HOV					0	0	0					

TABLE C-III (Concluded)

Case[1] - Basic Conf.	Stability Derivatives[2] $M_u g$	X_u	M_q	M_9	Maximum Control Moments Available M_{c_m}	L_{c_m}	N_{c_m}	Lag τ_e,τ_a	Delay d_e,d_a	Sub-Task[3]	Fixed Base, Pilot A P_{ML}	P_{LL}	P_{SL}	P_{NL}	Fixed Base, Pilot B P_{ML}	P_{LL}	P_{SL}	P_{NL}	Moving Base, Pilot B P_{ML}	P_{LL}	P_{SI}	P_{NI}
										XM	0.3		0		2.3		0		0.2		0.2	
LM10										YM		0.1	0			0.3	0			0		
-	1.0	-0.20	-3.0	-1.7	0.954	0.727	0.211	0	0	XQS	1.7		0		0.8		0		3.2		0.0	
BC4										YQS		0	0			0	0			0.05	0.0	
										TU	0	0	0	0	0	7.7	0	0	0.5	2.7	0	0
										HOV	0	0	0		1.6	0	0		0.2	0	0	
										XM	0		0		0.5		0					
LM13										YM		0	0			0.6	0					
-	1.0	-0.2	-1.1	-2.5	0.979	0.825	0.187	0	0	XQS	0		0		6.2		0					
BC6										YQS		0.6	0			2.4	0					
										TU					0.2	2.6	0	0				
										HOV					1.4	0.6	0					
										XM					0		0		0		0	
LM14										YM						0	0			0	0	
-	1.0	-0.2	-1.1	-2.5	1.068	0.900	0.204	0	0	XQS					0	0	0			0	0	
										TU					0	0	0	0	0	0.3	0	0
										HOV					0.2	0	0		0	0	0	
										XM	0		0									
LM15										YM		0	0									
-	1.0	-0.2	-1.1	-2.5	1.157	0.975	0.221	0	0	XQS	0		0									
BC6										YQS		3.0	0									
										TU	0.1	0	0	0								
										HOV	0	0	0									
										XM					0.6		0		0.1		0	
LM17										YM						0	0			0	0	
-	0.33	-0.05	-1.7	-4.2	0.396	0.457	0.132	0.3	0.1	XQS					1.5		0		2.1		0	
BC1										YQS						8.8	0			0	0	
										TU					0.3	0.3	0	0	0	0	0	0
										HOV					1.2	1.1	0		0.4	0.2	0	
										XM									0		0	
LM18										YM										0	0	
-	0.33	-0.05	-1.7	-4.2	0.432	0.498	0.144	0.3	0.1	YQS									0.6		0	
BC1										YQS										0	0	
										TU									0	0	0	0
										HOV									0.1	0	0	

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.

4. P_{SL}: Percent time that commanded moments exceeded installed limit on simultaneous control moment usage, (M_{C_M} + L_{C_M}).

TABLE C-IV

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT OF THE TIME FROM THE STUDY OF INTER-AXIS MOTION COUPLING

Vertical and Directional Parameters Listed in Table A-I

Case[1] - Basic Conf.	Stability Derivatives[2]				Motion Coupling Parameters				Sub-Task[3]	Fixed Base								Moving Base			
										Pilot A				Pilot B				Pilot B			
	$M_{u\delta}$	X_u	M_q	M_θ	M_p	L_q	$M_{\delta_a}/L_{\delta_a}$	$L_{\delta_e}/M_{\delta_e}$		M_{c_5}	L_{c_5}	Sim[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim[4]	N_{c_5}
									XM					0.48		0.67		0.36		0.43	
LC1									YM						0.39	0.66			0.24	0.49	
-	0.33	-0.05	-1.7	-4.2	2	-2	0	0	XQS					0.43		0.64		0.48		0.59	
BC1									YQS						0.56	1.05			0.35	0.78	
									TU					0.41	0.36	0.66	0.17	0.29	0.30	0.44	
									HOV					0.54	0.41	0.86		0.37	0.19	0.47	
									XM					0.61		0.88					
LC2									YM						0.54	0.96					
-	0.33	-0.05	-1.7	-4.2	4	-4	0	0	XQS					0.81		1.29					
BC1									YQS						0.91	1.57					
									TU					0.57	0.47	0.87	0.16				
									HOV					0.68	0.47	1.01					
									XM	0.40		0.58		0.39		0.64		0.34		0.42	
LC4									YM		0.40	0.56			0.38	0.64			0.2[illegible]	0.45	
-	0.33	-0.05	-1.7	-4.2	0	0	0.50	-0.50	XQS	0.58		0.79		0.47		0.68		0.36		0.42	
BC1									YQS		0.70	1.00			0.65				0.31	0.54	
									TU	0.36	0.40	0.58	0.11	0.28	0.30	0.47	0.23	0.27	0.24	0.38	
									HOV	0.37	0.29	0.51		0.37	0.34	0.65		0.29	0.18	0.38	
									XM	0.37		0.47		0.43		0.57		0.35		0.48	
LC5									YM		0.37	0.66			0.39	0.69			0.33	0.53	
-	0.33	-0.05	-1.7	-4.2	2	-2	0.25	-0.25	XQS	0.53		0.70		0.49		0.72		0.47		0.62	
BC1									YQS		0.72	1.23			0.63	1.10			0.33	0.61	
									TU	0.32	0.33	0.53	0.06	0.40	0.39	0.65	0.17	0.29	0.24	0.4[illegible]	0.05
									HOV	0.39	0.29	0.54		0.53	0.39	0.78		0.35	0.19	0.46	
									XM					0.87		1.06					
LC8									YM						0.71	1.28					
-	0.0	-0.05	-2.5	-0.5	2	-2	-0.25	0.25	XQS					0.85		1.09					
BC2									YQS						0.70	1.32					
									TU					0.90	0.68	1.34	0.17				
									HOV					0.77	0.47	1.03					

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.

4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function ($|M_c| + |L_c|$).

TABLE C-V

PITCH CONTROL-MOMENT AND THRUST-VECTOR-ANGLE LEVELS EXCEEDED 5 PERCENT OF THE TIME FROM THE STUDY OF INDEPENDENT THRUST-VECTOR CONTROL

Vertical and Directional Parameters Listed in Table A-I

Case[1] - Basic Conf.	Stability Derivatives[2]				Thrust-Vector Control Param.			Sub-Task[3]	Fixed Base				Moving Base	
									Pilot A		Pilot B		Pilot B	
	$\overline{M}_{\delta}$	X_u	M_q	M_θ	$\dot{\gamma}^4$	$\gamma_{\delta_e}^5$	$\dot{M}_{TS}^5$		M_{c_5}	TV	M_{c_5}	TV	M_{c_5}	TV
LI1 - BC1	0.33	-0.05	-1.7	-4.2	5	-	-	XM	0.33		0.29		0.25	
								XQS	0.29		0.34		0.33	
								TU	0.27	2.77	0.31	7.86	0.21	2.00
								HOV	0.29		0.30		0.25	
LI3 - BC1	0.33	-0.05	-1.7	-4.2	20	-	-	XM			0.32		0.28	
								XQS			0.33		0.27	
								TU			0.22	5.50	0.24	2.50
								HOV			0.29		0.27	
LI6 - BC4	1.0	-0.20	-3	-1.7	20	-	-	XM	0.93		0.93		0.80	
								XQS	0.88		0.89		0.86	
								TU	0.79	9.15	0.81	10.6	0.67	4.20
								HOV	0.72		0.75		0.68	
LI12 - BC1	0.33	-0.05	-1.7	-4.2	-	5	1	XM			0.35			
								XQS			0.39			
								TU			0.29	20.6		
								HOV			0.32			

1. Standard wind simulation; $\sigma_{u_g} = \sigma_{v_g} = 3.4$ ft/sec, $U_m = 10$ kts.
2. Symmetrical Configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; XQS, longitudinal quick stop; TU, ±180 deg turn-over-a-spot; HOV, precision hover.
4. Thumb switch thrust vector angle control, conventional attitude control.
5. Control stick thrust vector control, thumb switch attitude control.

TABLE C-VI

PITCH, ROLL AND YAW CONTROL-MOMENT LEVELS EXCEEDED 5 PERCENT OF THE TIME FROM THE STUDY OF RATE-COMMAND/ATTITUDE-HOLD CONTROL

Vertical and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

Case[1] - Basic Conf.	Stability Derivatives[2] $M_{\delta s}$	X_u	M_q	M_θ	Params. for Second-Order Dynamics ζ	ω_n	Sub-Task[3]	Fixed Base, Pilot A, M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	Fixed Base, Pilot B, M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	Moving Base, Pilot P, M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
LR1 - BC1	0.33	-0.05	-2	-8	0.39	2.8	XM					0.58		0.65					
							YM						0.58	0.90					
							XQS					0.89		0.98					
							YQS						0.75	1.01					
							TU					0.54	0.45	0.75	0.11				
							HOV					0.62	0.50	0.86					
LR2 - BC1	0.33	-0.05	-2	-40	0.16	6.3	XM					0.66		0.84		0.30		0.39	
							YM						0.59	0.93			.27	0.46	
							XQS					0.97		1.08		0.34		0.38	
							YQS						0.74	1.17			0.28	0.45	
							TU					0.57	0.47	0.88	0.37	0.24	0.34	0.44	
							HOV					0.69	0.48	1.07		0.77	0.21	0.40	
LR3 - BC1	0.33	-0.0[illegible]	-4	-8	0.71	2.8	XM					0.45		0.59					
							YM						0.42	0.72					
							XQS					0.59		0.82					
							YQS						0.66	1.00					
							TU					0.37	0.39	0.63	0.13				
							HOV					0.41	0.44	0.73					

TABLE C-VI (Continued)

Case[1] - Basic Conf.	Stability Derivatives[2]				Params. for Second-Order Dynamics		Sub-Task[3]	Fixed Base								Moving Base			
								Pilot A				Pilot B				Pilot B			
	M_u	X_u	M_q	M_θ	ζ	ω_n		M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
LR5 - BC1	0.33	-0.05	-6	-12	0.87	3.44	XM					0.44		0.58					
							YM						0.42	0.60					
							XQS					0.45		0.60					
							YQS						0.81	1.02					
							TU					0.35	0.42	0.55	0.12				
							HOV					0.43	0.41	0.62					
LR6 - BC1	0.33	-0.05	-6	-40	0.47	6.32	XM					0.48		0.62		0.24		0.37	
							YM						0.44	0.69			0.28	0.4[illegible]	
							XQS					0.50		0.65		0.35		0.38	
							YQS						0.56	0.77			0.26	0.44	
							TU					0.34	0.35	0.51	0.13	0.27	0.24	0.39	
							HOV					0.40	0.38	0.65		0.29	0.20	0.40	
LR8 - BC1	0.33	-0.05	-10	-20	-		XM	0.29		0.35									
							YM		0.20	0.40									
							XQS			0.44									
							YQS		0.47	0.59									
							TU	0.30	0.28	0.39	.059								
							HOV	0.23	0.19	0.37									

TABLE C-VI (Concluded)

Case[1] - Basic Conf.	Stability Derivatives[2]				Params. for Second-Order Dynamics		Sub-Task[3]	Fixed Base								Moving Base			
								Pilot A				Pilot B				Pilot B			
	M_{ug}	X_u	M_q	M_θ	ζ	ω_n		M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
LR10 - BC4	1.0	-0.20	-2	-25	0.20	5	XM					1.40		1.93					
							YM						1.06	1.60					
							XQS					1.37		1.90					
							YQS						1.03	1.67					
							TU					1.03	1.01	1.61	0.16				
							HOV					1.19	0.83	1.75					
LR11 - BC4	1.0	-0.20	-4	-16	0.50	4	XM					1.13		1.50		0.83		1.09	
							YM						0.90	1.63			0.53	1.13	
							XQS					1.15		1.49		0.83		1.02	
							YQS						0.99	1.75			0.48	1.08	
							TU					0.86	0.79	1.27	0.19	0.62	0.64	1.09	
							HOV					1.16	0.64	1.65		0.60	0.29	0.80	
LR14 - BC4	1.0	-0.20	-6	-26	0.61	5	XM					1.24		1.93		0.80		0.99	
							YM						0.92	1.76			0.57	1.07	
							XQS					1.05		1.28		0.75		0.90	
							YQS						0.71	1.22			0.59	1.13	
							TU					0.84	0.82	1.37	0.18	0.69	0.65	1.02	
							HOV					1.01	0.69	1.59		0.67	0.30	0.85	

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, ± 180 deg turn-over-a-spot; HOV, precision hover.

4. Sim : Simultaneous control moment usage, exceedance computations performed on the function $(|M_c| + |L_c|)$.

TABLE C-VII

PILOT COMMANDED AND TOTAL THRUST USAGE RESULTS FROM HEIGHT CONTROL STUDY

Longitudinal, Lateral and Directional Parameters Listed in Table A-I
See End of Table for Explanation of Notes

(a) Five-Percent Exceedance Levels for Pitching Moment, M_{c_5}, and Incremental Thrust Increase Levels, $(T/W-1)_5$

Case[1] - Basic Conf.	Parameters[2]			Lag, τ_h	Delay, d_h	Sub-task[3]	Fixed Base					
							Pilot A			Pilot B		
							M_{c_5}	$(T/W-1)_5$ for:		M_{c_5}	$(T/W-1)_5$ for:	
	Z_{w_a}	Z_{w_s}	T/W					$Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$	$Z_{\delta_c} \cdot \delta_c$		$Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$	$Z_{\delta_c} \cdot \delta_c$
HZ20 - BC1	-0.125	-0.125	1.10	0	0	XM	0.36	0.007	0.010	0.34	0.023	0.022
						YM		0.017	0.024		0.025	0.02[illegible]
						XQS	0.36	0.009	0.020	0.37	0.019	0.024
						YQS		0.034	0.035		0.034	0.034
						HOV	0.30	0.010	0.016	0.36	0.017	0.023
						LS	0.29	0.052	0.062	0.36	0.024	0.033
HZ21 - BC1	0	-0.25	1.10	0	0	XM	0.34	0.031	0.023	0.39	0.057	0.057
						YM		0.055	0.057		0.048	0.045
						XQS	0.47	0.030	0.029	0.37	0.026	0.029
						YQS		0.069	0.043		0.047	0.034
						HOV	0.29	0.029	0.038	0.33	0.014	0.023
						LS	0.69	0.067		0.32	0.061	0.067
HZ22 - BC1	-0.25	0	1.10	0	0	XM	0.36	0.024	0.018			
						YM		0.057	0.054			
						XQS	0.47	0.047	0.047			
						YQS		0.050	0.048			
						HOV	0.30	0.022	0.021			
						LS	0.30	0.070	0.060			
HZ23 - BC1	-0.25	-0.25	1.10	0	0	XM	0.37	0.008	0.006			
						YM		0.015	0.007			
						XQS	0.46	0.007	0.008			
						YQS		0.026	0.018			
						HOV	0.30	0.009	0.009			
						LS	0.30	0.030	0.052			
HZ1 - BC1	0	0	1.15	0	0	XM	0.39	0.042	0.042			
						YM		0.123	0.116			
						XQS	0.32	0.082	0.095			
						YQS		0.108	0.108			
						HOV	0.26	0.086	0.080			
						LS	0.34	0.122	0.121			
H[illegible]3 - BC1	-0.25	-0.25	>1.15	0	0	XM	0.34	0.009	0.017			
						YM		0.035	0.010			
						XQS	0.39	0.006	0.010			
						YQS		0.054	0.015			
						HOV	0.29	0.008	0.008			
						LS	0.26	0.028	0.045			

TABLE C-VII (Continued)

Case[1] - Basic Conf.	Parameters[2]			Lag, τ_h	Delay, d_h	Sub-task[3]	Fixed Base					
							Pilot A			Pilot B		
							M_{c_5}	$(T/W-1)_5$ for:		M_{c_5}	$(T/W-1)_5$ for:	
	Z_{w_a}	Z_{w_s}	T/W					$Z_{\delta_c}\cdot\delta c+Z_{w_s}\cdot w$	$Z_{\delta_c}\cdot\delta c$		$Z_{\delta_c}\cdot\delta c+Z_{w_s}\cdot w$	$Z_{\delta_c}\cdot\delta c$
HZ25 - BC4	0	0	> 1.15	0	0	XM				1.027	0.089	0.091
						YM					0.139	0.133
						XQS				0.88	0.167	0.167
						YQS					0.132	0.133
						HOV				0.78	0.098	0.098
						LS				0.83	0.169	0.158
HZ26 - BC4	-0.125	-0.125	> 1.15	0	0	XM	0.89	0.025	0.028	0.85	0.029	0.045
						YM		0.028	0.019		0.023	0.017
						XQS	0.98	0.015	0.015	0.98	0.010	0.009
						YQS		0.043	0.039		0.024	0.024
						HOV	0.74	0.034	0.030	0.87	0.027	0.023
						LS	0.84	0.070	0.069	0.87	0.034	0.043
HZ27 - BC4	-0.25	-0.25	> 1.15	0	0	XM	0.85		0.025			
						YM		0.017	0.039			
						XQS	0.84	0.009	0.034			
						YQS		0.016	0.038			
						HOV	0.72	0.008	0.035			
						LS	0.76	0.016	0.079			
HI2 - BC1	-0.125	-0.125	1.10	0.3	0	XM				0.30	0.038	0.045
						YM						
						XQS				0.37	0.035	0.038
						YQS					0.028	0.029
						HOV				0.30	0.023	0.027
						LS				0.29	0.048	0.053

TABLE C-VII (Concluded)

(b) Five-Percent Exceedance Levels for Pitching Moment, M_{c_5}, and Percent Time Commanded T/W of Pilot and SAS Exceeds Installed T/W

Case[1] - Basic Conf.	Parameters[2]			Lag, τ_h	Delay, d_h	Sub-task[3]	Fixed Base					
							Pilot A			Pilot B		
	Z_{w_a}	Z_{w_s}	T/W				M_{c_5}	P_{TL} for $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$	P_{TL} for $Z_{\delta_c} \cdot \delta_c$	M_{c_5}	P_{TL} for $Z_{\delta_c} \cdot \delta_c + Z_{w_s} \cdot w$	P_{TL} for $Z_{\delta_c} \cdot \delta_c$
HZ6 - BC1	-0.125	-0.125	1.02	0	0	XM	0.36	19.0	27.0			
						YM		38.0	65.0			
						XQS	0.48	21.0	30.0			
						YQS		14.0	60.0			
						HOV	0.32	10.0	14.0			
						LS	0.34	32.0	60.0			
HZ10 - BC1	-0.25	-0.25	1.02	0	0	XM	0.33	0.0	0.0			
						YM		3.0	0.0			
						XQS	0.39	0.0	2.0			
						YQS		25.0	29.0			
						HOV	0.29	2.0	1.0			
						LS	0.28	17.0	16.0			
HZ17 - BC1	-0.25	-0.25	1.05	0	0	XM				0.34	0.0	0.0
						YM					0.0	0.0
						XQS				0.39	0.0	0.0
						YQS					0.0	0.0
						HOV				0.36	0.0	0.0
						LS				0.32	3.0	8.0
HI1 - BC1	-0.125	-0.125	1.05	0.3	0	XM	0.39	16.0	16.0			
						YM		0.0	0.0			
						XQS	0.43	0.0	0.0			
						YQS		7.0	0.0			
						HOV	0.34	0.0	0.0			
						LS	0.34	2.0	4.0			

1. Wind simulation included mean wind, U_H = 10 kts. Thrust vector control available to trim longitudinal steady forces.
2. Symmetrical Configurations - lateral derivative has same value as corresponding longitudinal derivative.
3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; LS, landing sequence; HOV, precision hover.

TABLE C-VIII

YAW, PITCH AND ROLL CONTROL-MOMENT RESULTS
FROM THE DIRECTIONAL CONTROL STUDY

Longitudinal, Lateral and Vertical Parameters Listed in Table A-I
See End of Table for Explanation of Notes

(a) Five-Percent Exceedance Control-Moment Levels

Case[1] - Basic[2] Conf.	N_v	Directional Parameters Varied				Sub-Task[3]	Fixed Base								Moving Base			
							Pilot A				Pilot H				Pilot B			
		N_r	N_{c_m}	τ_ψ	d_ψ		M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
D1 - BC1	0.005	0	UL	0	0	XM									0.40		0.50	
						YM										0.26	0.43	
						XQS									0.43		0.51	
						YQS										0.27	0.49	
						TU									0.30	0.28	0.46	0.14
						HOV									0.35	0.18	0.40	
D2 - BC1	0.005	-0.5	UL	0	0	XM	0.39		0.52		0.42		0.57		0.38		0.47	
						YM		0.29	0.56			0.38	0.58			0.26	0.48	
						XQS	0.46		0.55		0.48		0.59		0.38		0.46	
						YQS		0.46	0.67			0.37	0.61			0.30	0.56	
						TU	0.29	0.29	0.46	0.13	0.31	0.33	0.49	0.14	0.28	0.22	0.39	0.14
						HOV	0.35	0.22	0.45		0.38	0.38	0.64		0.37	0.23	0.50	
D7 - BC1	0.005	-0.5	UL	0.3	0	XM	0.33		0.41		0.40		0.56		0.46		0.59	
						YM		0.29	0.44			0.44	0.68			0.34	0.62	
						XQS	0.30		0.41		0.40		0.50		0.46		0.58	
						YQS		0.38	0.57			0.44	0.62			0.32	0.63	
						TU	0.29	0.29	0.43	0.15	0.33	0.37	0.59	0.12	0.35	0.27	0.49	0.17
						HOV	0.29	0.18	0.39		0.38	0.33	0.58		0.40	0.25	0.62	
D8 - BC1	0.005	-0.5	UL	0.3	0.1	XM									0.42		0.63	
						YM										0.31	0.64	
						XQS									0.40		0.53	
						YQS										0.29	0.59	
						TU									0.30	0.24	0.45	0.16
						HOV									0.39	0.24	0.56	
D13 - BC1	0.005	-1	UL	0.3	0	XM									0.43		0.55	
						YM										0.28	0.59	
						XQS									0.39		0.53	
						YQS										0.29	0.56	
						TU									0.35	0.26	0.40	0.16
						HOV									0.39	0.27	0.55	

TABLE C-VIII (Concluded)

(a) Five-Percent Exceedance Control-Moment Levels

Case[1] - Basic[2] Conf.	N_v	Directional Parameters Varied				Sub-Task[3]	Fixed Base								Moving Base			
							Pilot A				Pilot B				Pilot B			
		N_r	N_{c_m}	τ_ψ	δ_ψ		M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}	M_{c_5}	L_{c_5}	Sim.[4]	N_{c_5}
D14 - BC1	0.005	-1	UL	0.6	0	XM									0.42		0.56	
						YM										0.28	0.52	
						XQS									0.42		0.57	
						YQS										0.30	0.61	
						TU									0.35	0.25	0.44	0.1[illegible]
						HOV									0.39	0.22	0.56	

(b) M_{c_5}, L_{c_5} and Percent Time Yaw Control-Moment Command Exceeded Installed Limit, P_{NL}

Case[1] - Basic[2] Conf.	N_v	Directional Parameters Varied				Sub-Task[3]	Fixed Base								Moving Base			
							Pilot A				Pilot B				Pilot B			
		N_r	N_{c_m}	τ_ψ	δ_ψ		M_{c_5}	L_{c_5}	Sim.[4]	P_{NL}	M_{c_5}	L_{c_5}	Sim.[4]	P_{NL}	M_{c_5}	L_{c_5}	Sim.[4]	P_{NL}
D20 - BC1		-1	0.10	0	0	XM									0.40		[illegible]50	
						YM										0.28	0.48	
						XQS									0.38		0.48	
						YQS										0.30	0.53	
						TU									0.30	0.29	0.45	13.20
						HOV									0.38	0.26	0.54	
D21 - BC1		-1	0.13	0	0	XM	0.39		0.56		0.40		0.39		0.38		0.47	
						YM		0.28	0.48				0.34			0.27	0.48	
						XQS	0.50		0.59		0.39		0.38					
						YQS						0.22	0.40			0.31	0.55	
						TU	0.30	0.29	0.47	7.50	0.33		0.31	1.00	0.28	0.26	0.39	6.70
						HOV	0.32	0.22	0.47		0.39				0.36	0.25	0.50	
D22 - BC1		-1	0.16	0	0	XM									0.40		0.58	
						YM										0.28	0.50	
						XQS									0.47		0.58	
						YQS										0.29	0.57	
						TU									0.34	0.26	0.44	1.10
						HOV									0.39	0.22	0.52	

1. Wind simulation included mean wind, U_m = 10 kts. Thrust vector control available to trim longitudinal steady forces.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

3. Key: XM, longitudinal maneuvering; YM, lateral maneuvering; XQS, longitudinal quick stop; YQS, lateral quick stop; TU, + 180 deg turn-over-a-spot; HOV, precision hover.

4. Sim.: Simultaneous control moment usage, exceedance computations performed on the function ($|M_c|$ + $|L_c|$).

APPENDIX D

SUMMARY OF FLYING QUALITIES DATA AND PILOT COMMENTS FROM CALSPAN PILOT EVALUATIONS

Flying qualities data (pilot ratings and pilot-selected control sensitivities) for the flight simulator evaluations with Calspan pilot B are summarized in Table D-I. Another Calspan pilot participated briefly in the UARL program but did not perform flying qualities investigations. Calspan pilot B evaluated both lateral and longitudinal control test cases and height control cases. Turbulence effects, control lags and delays and control-moment limits were evaluated in the longitudinal and lateral control investigation (Table D-I(a)). The interactive effects of height velocity damping and thrust-to-weight ratio were evaluated in the height control study (Table D-I(b)).

Edited pilot comments from the Calspan pilot B evaluations are summarized in Table D-II. Comments for the longitudinal and lateral control test cases are shown in Table D-II(a) and those for the height control test cases are contained in D-II(b).

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TABLE D-I

FLYING QUALITIES RESULTS FROM CALSPAN PILOT EVALUATIONS

Height and Directional Parameters Contained in Table A-I
Pilot Comments Given in Table D-II

(a) Longitudinal and Lateral Control

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Root	Maximum Control Moments			Turbulence	Lag	Delay	Moving Base		
		M_u	X_u	Z_w	M_q		$-\zeta\omega_n \pm j\omega_d$	M_{c_m}	L_{c_m}	N_{c_m}	$\sigma_{u_g}=\sigma_{v_g}$	$\tau_e=\tau_a$	d_e-d_a	M_{δ_e}	L_{δ_a}	PR
CL1	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.89	UL	UL	UL	1.7	0	0	0.447	0.280	7.0
CL2 CL3	[illegible]	1.0	-0.05	-1.1	[illegible]	-0.5	-0.30±j1.47	UL UL	UL UL	UL UL	0 1.7	0 0	0 0	0.370 0.370	0.320 0.3[illegible]	[illegible] [illegible]
CL4 CL5	[illegible]	1.0	-0.05	-2.0	0	-2.0	0.08±j0.68	UL UL	UL UL	UL UL	0 1.7	0 0	0 0	0.320 0.320	0.3[illegible] 0.365	8.5 10.0
CL6 CL7	BC4	1.0	-0.20	-3.0	-1.7	-2.5	-0.35±j0.64	UL UL	UL UL	UL UL	0 1.7	0 0	0 0	0.321 0.321	0.365 0.365	3.0 4.5
CL8 CL9	[illegible]	0.33	-0.10	-1.7	-4.2	[illegible]	-0.81±j1.89	UL UL	UL UL	UL UL	0 1.7	0 0	0 0	0.370 0.386	0.341 0.402	3.0 7.0
CL10 CL11 CL12 CL13	BC4	1.0	-0.20	-3.0	-1.7	-2.5	-0.35±j0.64	UL UL UL UL	UL UL UL UL	UL UL UL UL	0 0 0 0	0 0.3 0.6 0	0 0 0 0.1	0.473 0.523 0.50[illegible] 0.535	0.273 0.220 0.337 0.341	3.0 3.0 5.0 2.5
CL14 CL15 CL16 CL17 CL18 CL19	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.89	0.103 0.216 0.216 0.288 UL UL	0.124 0.245 0.249 0.332 UL UL	0.048 0.006 0.096 0.128 UL UL	0 0 0 0 0 0	0 0 0 0 0 0	0 [illegible] 0 0 0 0	0.604 - 0.460 0.447 0.447 0.500	0.234 - 0.361 0.230 0.280 0.310	10.0 9.0 3.5 4.0 5.0 7.0

(b) Height Control

Case[1]	Basic Conf.	Stability Derivatives[2]				Real Root	Complex Root	Height Damping, Thrust-to-Weight Parameters			Moving Base	
		M_u	X_u	Z_w	M_q		$-\zeta\omega_n \pm j\omega_d$	Z_{w_a}	Z_{w_s}	T/W	Z_{δ_c}	PR
CH1 CH2 CH3	BC4	1.0	-0.20	-3.0	-1.7	-2.5	-0.35±j0.64	0 -0.25 -0.35	0 -0.25 -0.35	UL UL UL	3.20 3.20 3.20	10.0 5.0 3.5
CH4 CH5 CH6 CH7 CH8 CH9 CH10 CH11	BC1	0.33	-0.05	-1.7	-4.2	-0.13	-0.81±j1.89	-0.175 0 -0.05 -0.175 -0.25 -0.05 -0.125 -0.175	-0.175 -0.35 -0.05 -0.175 -0.25 -0.05 -0.125 -0.175	1.02 1.02 1.05 1.05 1.05 1.10 1.10 1.10	8.20 8.00 3.20 1.51 1.51 5.44 1.51 6.30	3.5 4.0 6.0 5.5 3.0 7.5 5.0 3.0

1. Mean wind = 0 for all Calspan pilot evaluations. For height control $\sigma_{u_g} = \sigma_{v_g} = 0$ for cases CH1-CH3 and $\sigma_{u_g} = \sigma_{v_g} = 1.7$ ft/sec for cases CH4-CH11.

2. Symmetrical configurations - lateral derivative has same value as corresponding longitudinal derivative.

TABLE D-II

PILOT COMMENTS FROM CALSPAN PILOT EVALUATIONS

(a) Longitudinal and Lateral Control

Case CL1 BC1 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 1.7$ $M_{\delta_e} = 0.487$ $L_{\delta_a} = 0.280$ PR 6

Control sensitivities - I did get adequate roll control; however, the configuration is such that it's difficult to stop it where you want, so you have to anticipate quite a bit. Adjusted sensitivities to give enough quickness of response so I would attempt to stop without having to anticipate as much. Then there was a tendency to oscillate so I finally compromised and accepted the sensitivities that I have now. Air taxi around the square - it's very difficult to remain over the spot on the ground, primarily because I'm behind the airplane or I'm overcontrolling in attempting to maintain a position. It does seem that pitch response and bank angle response are quite good but the aircraft response in translation is very sluggish in both directions, both in trying to get it started and in stopping it. Once you get it started it's quite difficult to stop it with any precision at all. You approximate the task and that's about all you can do. There is a low level of precision here. If I concentrate very hard I can usually stay within the 10-ft square. Holding heading is no problem. There is some change in altitude, but not very much -- maybe 7 or 8 ft. Quick-stops - Don't really have any precision, you just have to make some pretty large inputs. I managed to do it a couple of times fairly well, but it was strictly a hit-or-miss proposition. Turning over a spot - That's a problem; the big difficulty is to stay within 10 to 20 ft of the center of the square. Hover - The ability to maintain precision hover is quite poor as far as attitude and angular rates are concerned; however, it's not bad. As usual, have quite a bit of trouble laterally. Seems that I'm sliding back and forth all the time. The motion starts quite subtly, but once it starts it is difficult to stop. Overall evaluation - The major objectionable features are the sluggishness in response and control of the displacements. Favorable features include the fact that height control is pretty good, heading control is no problem and there are really no oscillatory tendencies at all in any direction.

Case CL2 BC2 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_e} = 0.380$ $L_{\delta_a} = 0.320$ PR = 7

Case CL3 BC2 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 1.7$ $M_{\delta_e} = 0.380$ $L_{\delta_a} = 0.320$ PR = 9

With turbulence (CL3) I would say, for all practical purposes, that the aircraft is unflyable. I can maybe keep it in the sky but the excursions are very large and I get the feeling I really don't have much control over the aircraft. I didn't get a chance to do anything in the way of maneuvering. All I was trying to do was to hover over a spot, and I wasn't able to do that. So I tried various gains on the cyclic both in pitch and roll and just didn't feel it was very good. I think it improved some when I went up to higher sensitivities, but not sufficiently that I would accept the airplane. This cut down the level or magnitude of the excursions, but I still didn't think it was a flyable or acceptable airplane and I couldn't do the task. So then I flew it without turbulence (CL2). Without the turbulence I was able to do the maneuvers to some extent. I get the impression that, even without turbulence, there are some external disturbances. These may be inadvertently pilot-induced. Certainly it's a tremendous difference between turbulence in and turbulence out. With turbulence (CL3) I would have to reject the configuration completely because at some point you probably will lose it, especially if the turbulence were any higher. Now, in smooth air, it did seem there was some lag in response to control inputs, about all axes, in spite of the fact that the height control is pretty good. I'd have to move the collective only a number of times. I think I was able to initiate the motion alright but precision of stabilizing velocities, etc., wasn't very good at all. I don't think my hover capability was real good although I did manage to make some turns in both directions and most of the time stayed within the square. There seems to be quite a bit of change in attitude, pitch primarily. Tried some quick stops. The airplane responds sluggishly; there seems to be a fair amount of lead required to either stop lateral motions or longitudinal motions. In turning over a spot, no real problem stopping on a heading. There is apparently no cross-coupling between the rudder and the cyclic. Probably would have been able to land this, at least in smooth air. In regard to secondary dynamics, in the higher rate maneuvers there was some cross-coupling. The major objectionable feature was the lack of precision with which I can initiate and stabilize velocity and position over the surface. I did manage to do some 360's fairly good in hover, but that's about the only thing I was able to do fairly well.

Case CL4 BC3 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_e} = 0.320$ $L_{\delta_a} = 0.365$ PR = 8.5

Case CL5 BC3 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 1.7$ $M_{\delta_e} = 0.320$ $L_{\delta_a} = 0.365$ PR 10

Tried it with turbulence (CL5) and found it completely unacceptable, probably a 10 rating. I flew it for a couple of minutes. In smooth air (CL4) I tried quite a few gearings and I thought that might help but it didn't. It looks like lightly damped roll modes and I'm not sure about pitch. There were times where it almost felt like the airplane wanted to go on its own, but in any case didn't have precision of control. I had more trouble in roll than in pitch. Maneuvers not very successful. Regardless of control sensitivities, I never really felt I had good lateral control. I didn't have nearly as much trouble in pitch as in roll. Not able to establish any decent bank angle; very easy to overcontrol. I didn't like it, couldn't really stop or hover precisely. Not really able to stay within ground track limits. Quick stops - Not really very good at all; I tried some but seems like the airplane wants to take off, especially in the lateral quick stops. Turning over a spot - Didn't look real bad. It does seem that, once you get the airplane under reasonable control and get everything steadied out reasonably well, it can be held reasonably well.

TABLE D-II(a) (Continued)

Case CL6 BC4 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ M_{δ_e} = 0.321 L_{δ_a} 0.36[illegible] PR 3

Case CL7 BC4 M_{c_m} = UL L_{c_m} UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 1.7$ M_{δ_e} = 0.321 L_{δ_a} = 0.365 PR = 4.5

It was quite a bit more effort to try to do the task in turbulence (CL7) but I was able to do that and even hover, say, fair. I could even keep within the 7-ft square. Lot of control activity in the turbulence, however. The configuration does seem to have reasonable stability and damping and the responses to control inputs appear to be reasonable with the particular gearings I chose. In smooth air the response to control inputs was fair. It does still seem that there are some lags in the initial responses to control inputs. I also did a fair amount of height control power inputs. I was able to establish displacements and velocities with reasonable precision in smooth air. Hovering capability was reasonably good. Could do the turns over a spot reasonably well. I really don't see anything strongly objectionable; the biggest thing probably are some lags in response to control inputs, but they are not really so bad. Could do it fairly well. Have some difficulty with bank angle, but it's probably me. So in smooth air I would say the aircraft was pretty good. I think performance in smooth air was satisfactory without improvement. In turbulence the work level certainly goes up quite a bit and maybe this is just a matter of proficiency. In turbulence the pilot compensation and workload are really fairly high.

Case CL8 BC5 M_{c_m} = UL L_{c_m} UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ M_{δ_e} = 0.370 L_{δ_a} = 0.341 PR = 3

Case CL9 BC5 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 1.7$ M_{δ_e} = 0.386 L_{δ_a} = 0.402 PR = 7

Flew this in smooth air first (CL8) and I thought overall it was an excellent configuration. The only thing I noticed was a tendency to bobble the airplane a little in pitch. Whether there is lightly damped pitch oscillation here I don't know. Could have just been closed-loop. Noticed this particularly when I tried to make a fairly rapid attitude change. The control sensitivities seemed to be adequate in smooth air. I then flew short time in turbulence (CL9) and felt the need to increase the control sensitivity to be able to offset some of the gusts. Not really sure which was better: without the higher sensitivity it seemed that I just didn't have sufficient control to keep the aircraft excursions small enough. On the other hand, with the higher gearings it did seem that I got into more high-frequency PIO's. Wasn't sure which to take, but it did seem that this gearing I have in turbulence (CL9) is better suited for precision control in doing the hover. The following comments are in smooth air. Response to control input seemed to be reasonable, although there were times when I felt it was a little sluggish, but I did seem to be able to stop the thing without needing a lot of lead, so maybe the damping is pretty good. The controllability of position and velocity seemed reasonable. Could hover very well. Could do turns over a spot very well. Very rarely went outside the 7-ft square. Could do the quick stops quite well although it did seem that I couldn't really generate high enough velocities with the control power I had. In other words, for the quick stop I would have expected to get a little higher speed going and make it much quicker, but this may be a function of the gearing I chose or it may just be a function of the dynamics of the aircraft. In any event, I was able to do all of the tasks with what I considered to be pretty good precision. The only possible objectionable feature is that the response, maybe initial response, to control inputs could be a little slow and possibly control power maybe was a little low. This may be my fault, going with the gearing I had. I don't really see that there is anything objectionable about it. In smooth air I certainly would rate it satisfactory without improvement for the task I was doing, with only negligible deficiencies or some mildly unpleasant deficiencies. In turbulence, I had quite a bit of trouble. The performance in turbulence certainly was not what I would consider very good so that the airplane would go into the deficiency-warrant-improvement category.

Case CL10 BC4 M_{c_m} UL L_{c_m} UL N_{c_m} UL σ_{u_g} σ_{v_g} 0 M_{δ_e} 0.478 L_{δ_a} 0.273 PR 3

No comments due to defective recording.

Case CL11 BC4 M_{c_m} UL L_{c_m} UL N_{c_m} UL σ_{u_g} σ_{v_g} 0 $\tau_e = \tau_a = 0.3$ M_{δ_e} = 0.[illegible]3 L_{δ_a} 0.[illegible] PR 3

I didn't feel any great need to try a range of control sensitivities, so I left them where they were initially. Air taxi around the square - Response to control inputs seemed a little sluggish about all axes, but was able to stabilize and hold desired velocities. However, with these gearings the rates were generally rather small for fairly large inputs, but I felt comfortable with it. Some lag in initiation of the motion. Was able to stop the motion rather rapidly but it did take fairly large attitude changes to do it. Could actually overcontrol quite a bit and still be able to stop the motion pretty close to where I wanted it. Was able to come to a hover at the corners fairly well. Attitude changes required were fairly large, but mainly because I would wait quite awhile before I would try to stop it. Ability to remain within ground track was pretty good. Was able to hold heading well. Control deflections were very often on the fairly large side. Ability to hold heading wasn't bad at all. Control motions were fairly large. Turn over a spot - I thought my performance was very good as far as making turns and hovering; height control was no particular problem. Could initiate and maintain the turn rate. It seems to me it's strictly mechanical: you put the rudder in a certain amount, set up some kind of yaw rate and that's it. You can practically take your feet off the rudder and it will just stay there, and when you get within 5 or 10 degs of where you want to stop, just put in the opposite rudder. Doesn't seem to be any particular trouble as I can stop at a preselected heading very well. No wing tilt control used. Certainly I could establish hover quite well. Control was adequate for vertical landing. I would probably say the most objectionable feature was that the aircraft wasn't very responsive. The favorable feature is that I can do all the maneuvers with good precision.

Case CL12 BC4 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ $\tau_e = \tau_a = 0.6$ $M_{\delta_e} = 0.509$ $L_{\delta_a} = 0.237$ PR = 5

Once you establish a velocity while maneuvering, it can be held reasonably well. The problem was in initiating it in such a way that the pilot didn't oscillate or develop a PIO. Ability to stop precisely was a little problem because of the dynamics and the necessity for the pilot to reduce his gains so he didn't get into a PIO. I think there are times when the attitude changes are rather large, especially in pitch, but in fact the attitude changes are really fairly small. Would rate the ability to remain within ground track limits, to hold headings and to hold altitude as fair. Seemed like the altitude control was not quite as precise as desired, mainly because I was concentrating more on attitude inputs because of this tendency to get into a PIO. Did seem that I was making some fairly large control deflections in pitch and roll. To get large bank angle (10 deg max) rapidly and then try to stop it resulted in getting behind the oscillation. That part of the problem was strictly pilot-induced. For small corrections, didn't have that trouble at all. Really noticed this only in the large inputs and when I required large, high rates. Don't think I was able to accomplish what you might consider a quick stop maneuver. If I tried I just felt that I didn't know whether I could stop the motion, because I got into a pilot oscillation. Don't think there were any excessive attitude changes; was just cautious about getting the aircraft to move laterally and maintain reasonable rates so I could avoid oscillation. Ability to hold heading and altitude was somewhat degraded, I think mainly because I was more worried about stopping it. Turning over a spot didn't provide much trouble. Would be drifting a little but could make corrections. Only time I felt in trouble was when attitude rates got high. The objectionable feature was that large attitude changes had to be made slowly to avoid getting into an overcontrol situation and PIO. However, for small amplitudes and small corrections, and when things were fairly well stabilized, the precision of control wasn't bad at all. Special piloting technique is to make control inputs so as to stay away from oscillatory tendency.

Case CL13 BC4 M_{c_m} = UL L_{c_m} = UL N_{c_m} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ $d_e = d_a = 0.1$ $M_{\delta_e} = 0.355$ $L_{\delta_a} = 0.341$ PR = 2.5

Tried higher lateral and longitudinal sensitivities and rapid, large amplitude maneuvers. With the higher sensitivities I could do a pretty good job although I seemed to be a little more oscillatory, so I decided to reduce the gains to roughly the initial values. Air taxi around the square - Response to control inputs seems a little sluggish. However, it's not really difficult to stabilize and hold desired velocities even though a little on the slow side. Ability to stop precisely not too bad. Seemed to be a relatively easy thing to stop precisely. Attitude changes may be a little on the high side. Ability to remain within ground track limits was quite good. Could hold heading and altitude quite well. Control deflections at times seemed to be on the large side with this gearing. For example, to get 5 deg of bank angle requires almost full throw, although I'm not hitting the stops. Didn't use any trim. Quick stops - With this gear ratio you don't really pick up very large velocities. After making an input it takes a little while for the velocity to pick up. To determine how much to lead it to stop didn't seem to be a very difficult thing. Ability to hold heading and altitude was quite good. Control motions required are substantial but manageable. Ability to hover over a spot was very good. Height control no problem. Pitch and roll control quite good. Ability to initiate and hold turn rates no problem and stopping on a preselected heading no problem. I was very happy with the precision of the hover, precision of the turns, ability to stop the motions; even though there are some lags in the system they were still quite noticeable. Control activity for vertical landing is probably fairly normal for a VSTOL airplane. The basic good feature is that the performance is quite good without excessive workload. No particular piloting techniques. I think it's acceptable and satisfactory, probably doesn't need any improvements unless you are looking for a highly responsive aircraft.

Case CL14 BC1 M_{c_m} = 0.308 L_{c_m} = 0.124 N_{c_m} 0.040 $\sigma_{u_g} = \sigma_{v_g} = 0$ M_{δ_e} = 0.004 L_{δ_a} = 0.234 PR = 10

There is no question that this is an unacceptable configuration. I tried a range of longitudinal control sensitivities because I got into a longitudinal PIO which was so large and I was so far behind it that I in effect lost control. Increased the sensitivity; this seemed to improve things somewhat as long as I flew the airplane very tightly and with small amplitude displacements. Could be the pitch rate and attitude both coupled in here to get me into trouble. If I got the aircraft moving forward pretty fast in trying to quick stop, it required very large pitch attitude to stop it. This is when I got into what appeared to be a very large amplitude situation where, in effect, I lost control. Did this about three or four times and went back to initial conditions. One can control the aircraft and do the maneuver task but you have to do it with small amplitudes and slow rates in pitch attitude. Once you get into large amplitude displacements and high pitch rates, then, in effect, control was lost. Would have to rate this an unacceptable configuration. It feels like control power was way down and so I just can't accept the airplane.

Case CL15 BC1 M_{c_m} = 0.216 L_{c_m} = 0.248 N_{c_m} - 0.096 M_{δ_e} and L_{δ_a} Unknown PR = 6

A pretty lousy configuration; not nearly as bad as the one I just had (CL14), but has similar characteristics, although the biggest problem with this one appears to be in controlling longitudinal position. Don't seem to have much control of forward and aft velocities or of being able to stop it with any degree of precision. Lateral control is not very good, but does seem to be a little better than longitudinal. Initial response to control inputs seems to be slow; however, once you get it started you do seem to have difficulty establishing a particular rate. It does seem to take a large pitch attitude change to get it moving and to stop it. Don't seem to have any idea when to make control reversals to stop it precisely. Don't think my ground track was very good in any case. Always had some heading problems here because I'm very often inadvertently putting rudder in when I'm trying to turn or bank. Where it stopped in the quick stops was unpredictable. Can't stop it where I want it. Then trying to hold it was also a problem. Turning over a spot was quite ragged. Errors were on the order of 15 or 20 ft from the center. Tried flying it very tightly but just wasn't really able to accomplish it. Performance

was quite poor. Trying to maintain a hover resulted in position errors on the order of ±10 to 15 ft. Not sure I have adequate control for vertical landing. I suppose you might have some velocity, and just go ahead and land it, but trying to hit a spot is quite difficult. Lots of control activity. Objectionable features are the fact I just don't seem to know what kind of inputs to make to stop motions or initiate motions of the magnitude and the precision desired. No real special piloting techniques except that you try to second-guess or anticipate the inputs. Basically it's a very poor configuration from the standpoint of precision of control and performance.

Case CL16 BC2 $M_{c_m} = 0.216$ $L_{c_m} = 0.249$ $N_{c_m} = 0.096$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_c} = 0.460$ $L_{\delta_c} = 0.361$ PR = 3.5

I tried several control sensitivities. At the higher values, get into some PIO problems and some overcontrol problems, so I reduced them a little. There is some lag in the response to control inputs and it does take a fair amount of attitude change to get things moving, but it's not excessive. Can maintain velocities once I've established them as long as they are not too high. I do seem to run into some problems if I increase my gain and make larger inputs; in other words, if the rates are fairly high and it takes large amplitude attitude changes to stop the motion. Then I get into some overcontrol and oscillatory tendencies. For low and moderately low velocities I can stop fairly well on the corners. Performance on ground track wasn't too bad. Holding heading was OK. Quick stops - Wouldn't say these are really good quick stops. The main problem is that I relate the quick stop with high rate velocities and large amplitude pitch or bank angles, where I get into trouble. So I've been a little hesitant to get it going too fast. I did get into some PIO laterally one time when I made a fairly rapid quick stop. Turn over a spot - That actually went very well as long as I had a good stable rate of turn and not too fast. Was able to stay just about in the center of the spot most of the time. At the higher rates I went a little outside the square, maybe about 5 ft or so. I was fairly happy with the hover and turns, fairly happy with the low rates, both lateral and longitudinal, not too happy with the quick stop. Generally, it takes a moderate amount of concentration. I think I did induce some sort of lateral oscillation at times, especially when I felt I had to make some pretty rapid inputs.

Case CL17 BC1 $M_{c_m} = 0.262$ $L_{c_m} = 0.339$ $N_{c_m} = 0.228$ $\sigma_{u_g} = \sigma_{v_g} = 0$ $M_{\delta_c} = 0.447$ $L_{\delta_c} = 0.250$ PR = 4

Didn't do too much on the gearings. I seemed to be able to fly the airplane pretty well so I only changed the longitudinal sensitivity a little. Response to control inputs seems to be pretty fair. Was able to initiate motions but it's not as responsive as I would like it. As long as I maintain u and v to moderately low values, there is no problem in maintaining desired velocities. There is a lag in the response in u and v to control inputs, but the attitude changes required to get the airplane to move in the x and y direction seem to be only moderate. Pitch attitude changes and roll attitude changes to stop the motions seem what I would rate as moderate. Would prefer to have smaller changes required but it's not really too bad. Precision to stay over ground track was fair also. Did take some effort, but performance was not too bad. Holding heading was not a problem and altitude control was good and control deflections were moderate. Quick stops - Don't think it's as good as I would like to see it but it's really not too bad either. Does take pretty large attitude changes to perform a quick stop. Turn over a spot - Was fair to good; at least I didn't have to work too hard and I could probably stay within about 10 ft of the center of the square. No problems initiating and stopping the turn. Again I did not push the rate. In the hover the performance was pretty good. Did have to work fairly hard but not excessively hard to do a reasonable job, although you're always making inputs. Certainly adequate for vertical landing and control activity would be considered as moderate to moderately high. Some slight cross-coupling between lateral and longitudinal modes. I guess the only objectionable feature I could see was the lack of responsiveness of the airplane in the u and v velocities, ability to stop precisely, and the small lag in response of the aircraft to moderate control inputs. Also, the attitude changes are maybe a little higher than would like. You can make some improvements on the airplane. Desired performance requires moderate pilot compensation.

Case CL18 BC1 M_{c_m} UL L_{c_m} UL N_{c_m} UL $\sigma_{u_g} = \sigma_{v_g}$ 0 M_{δ_c} 0.447 L_{δ_c} = 0.280 PR = 5

Tried several values of control sensitivity. Increased the sensitivity and didn't particularly like it because I got into some sort of pilot-induced oscillation, mainly in roll. There is still some lag in the response in the displacements and velocities of the aircraft. This was a sort of moderately difficult configuration to fly. Was able to do some things with pretty good precision, but it did take a lot of concentration. It did have a tendency to lag the control input, you had to anticipate stopping the motion of the aircraft laterally and longitudinally. Pitch response, roll response, yaw response all pretty good. Responsiveness in the initiation of motion and the stopping of the motion in the x and y directions was affected by lags in the system. Was difficult to stabilize and hold desired velocities. Then to try to stop it at any precise point was also somewhat difficult. I was able to hover pretty well, but it did take quite a bit of concentration. In doing so, there were some excursions in height but that was easily compensated with collective inputs. Height control was quite adequate; good damping in height. There is sort of a corkscrew effect when you start turning, depending on the rate at which you turn. There is a tendency to drop down in altitude. Sure there is a loss of lift as it does require some noticeable power input to maintain altitude. Had a tendency to lose altitude in the turn over a spot. Also seemed to be power required when I made some rapid lateral and longitudinal displacements. As far as precision around the ground track, x and y was sort of rough, especially in the y direction. I was either too far ahead or too far behind the spot. Quick stops - It's sort of a hit-or-miss proposition, although I managed to stop at the spot fairly well, but trying to hold it there was not easy. There did seem to be some fairly large control motions required. Turning over a spot - I think the ability to stay over the spot was only fair, I was always making corrections. Didn't make very fast turns. With these moderate turn rates I was able to stop it within about 15 deg of desired heading. Hover precision was fair, but I had to work fairly hard at it. Certainly adequate for vertical landing and control activity was almost constant. There were some x cross-coupling effects between longitudinal motions and lateral or bank angles. I always had that problem. I guess the most objectionable feature is the fact that you do have to anticipate stopping of x and y motion and pitch attitude changes. Pitch attitude changes seem to be fairly large to maneuver. Overall, it does require moderate to considerable pilot compensation to do most of the tasks, especially the quick stops.

TABLE D-II(a) (Continued)

Case C119 3C1 M_{c_m} = UL L_{c_m} = UL N_{c_n} = UL $\sigma_{u_g} = \sigma_{v_g} = 0$ M_{δ_e} = 0.500 L_{δ_a} = 0.310 PR = 7

This was not a very good configuration. I played around a little with the gearings, but the final values are essentially like the previous configuration. Even for relatively small amplitude displacements and rates, I just didn't think the precision of control and the precision of the task were adequate. Don't believe I ever felt I completely lost control, but there were times when very large excursions were obvious. Quick stops - I could stop it, but then I couldn't maintain position at the stopping point. Then trying to bring it back to hover was quite a problem. Could probably stop the turn on a heading within about 15 deg. Precision of hover was fair, but it did take a pretty fair amount of concentration. I would probably be able to land, although I'd have to be quite careful with it. Height control, however, didn't seem to be a big problem, although there was one maneuver where I think I left the altitude go all the way down to 20 ft. I guess the primary objection is the initiation of translational motion is sluggish and once you get the motion started it's difficult to stop it. Pitch control is certainly quite adequate. Lateral control seemed a little sluggish. The attitudes required to stop the airplane once you get it moving are fairly large, especially in pitch. Didn't see anything too favorable about the configuration. There is no pitch or lateral oscillation that is highly objectionable, so the damping in pitch and roll is pretty good. The problem is along the axes in translation and also the large displacements in bank angle and pitch attitude that are required to get the airplane to move and stop.

TABLE 7. I(b) (Continued)

(b) Height Control

Case GH1 $Z_{w_a} = Z_{w_s} = 0$ T/W = UL $Z_{\delta_c} = 3.20$ PR = 10

Primary task was to evaluate ability to maintain height control while doing basic tasks. It's quite obvious you've absolutely no stability, no damping in height control, so the pilot starts off chasing altitude. The task is very, very severe. I was overcontrolling very, very much with the collective. I tried it again much more carefully and was actually able to get off the ground and establish about 50 ft and had pretty good control of altitude for a short time, maybe on the order of a minute or two, and was also able to hover over the spot at the same time fairly well, but was spending much time controlling altitude. So everything looked good; then I tried to start the maneuver. As soon as I did this, the altitude changed a little, so I tried to chase it with larger and larger collective inputs. Was going down to about 40 ft and up to about 80 or 90 ft. That's pretty poor. It was obvious that practically all my time would have to be devoted to height control and there would be very little time to do anything else with the aircraft. On the basis of height control alone, I would have to rate this configuration completely unacceptable. Control will be lost in some portion of required operation.

Case GH2 $Z_{w_a} = Z_{w_s} = -0.25$ T/W = UL $Z_{\delta_c} = 3.20$ PR = 5

Required a fair amount of monitoring of height control. The best I could do was to maintain altitude about ±20 to ±10 ft, but this took a fair amount of effort. I did all of the maneuvers. Didn't really think that these maneuvers were too bad. Some degrading might have occurred in performance due to time spent monitoring height control. Always shooting for ±5 ft, but this time I doubled that on the average to ±10 ft. Air taxi around the square response to controls really wasn't too bad. Was able to initiate motion in each direction. General comments - Essentially, I had a fair amount of monitoring on height control with rather large excursions. Say as much as 20 ft high and about 15 ft low from the nominal 50 ft that I'm shooting for. On the average, however, height control was about ±10 ft. Required reasonable amount of monitoring. Didn't choose any control sensitivity, just accepted what was here as being reasonable. Could do all the maneuvers reasonably well. However, during the more rapid and larger amplitude maneuvers I had to monitor the height a little more carefully because it would tend to either climb or descend as I made these large amplitude inputs. Most objectionable feature would be the height control; I would certainly like to have it be better. Favorable feature, I think, was the fact that, in spite of height control, I was still able to do all maneuvers reasonably well.

Case GH3 $Z_{w_a} = Z_{w_s} = -0.35$ T/W = UL $Z_{\delta_c} = 3.20$ PR = 3.5

Control sensitivity - Finally chose this one, which is a little lower gain than would have really liked from a standpoint of initial response. With higher sensitivities, got into other little problems like a tendency to overcontrol some, so I finally backed off. Taxi around the square response to inputs was fair. Ability to stabilize and hold desired velocities was fair. Could stop and come to a hover at the corners reasonably well, although again it takes fairly large and rapid inputs to stop. It does take fairly large pitch and roll attitudes; the bank angles are usually less than 5 deg and in pitch less than 5 deg. However, was able to maintain ground track quite well and no problem in holding heading because you just keep your feet off the rudders in effect, and the friction holds it once you establish that you have no rate of turn. Altitude control - Spent some time on it; could maintain altitude if I wanted to within ±5 ft for normal maneuvering. Not true when I went into large amplitude, very rapid or at least attempted to make very rapid inputs to establish higher rates. Here height control problem became a little more obvious. Quick stops - Could stop quickly but, considering that rates are fairly low, the attitude changes appeared to be fairly high. So attitude control doesn't seem to be much of a problem; height control a little bit of a problem, definitely noticeable that you do have to spend some time on it. Can initiate and hold turn rates without problem; can stop on preselected heading even at very high rates. Didn't use any of the wing tilt control. Precision hover - Vertical landing - Was able to establish and maintain precise hover quite well, a little skidderish but not really too bad; could generally stay well within the 7-ft square. The dynamics of one axis did not affect the evaluation of another. Overall evaluation - Somewhat objectionable feature was that you have to look at the height control, but it really wasn't that big a feature. Was reasonably satisfied that I could meet my criterion of ±5 ft, but to do that it requires maybe a little more time and cross reference than is desirable. Favorable features - The fact that I can do all the maneuvers with reasonable precision in a fairly good way. No special piloting technique.

Case GH4 $Z_{w_a} = Z_{w_s} = -0.175$ T/W = 1.05 $Z_{\delta_c} = 4.20$ PR = 3.5

Control sensitivities - Added a little sensitivity, it seemed to be a little better. I would say generally this was a fair configuration. Air taxi - The precision of control is still not really as good as I would like it. The small sensitivity change helped some. Still get the feeling there are appreciable lags from collective input and in stopping the rates of descent or rates of climb I can find a fairly well stabilized altitude with some effort. It takes several power inputs and cross-checking between the display and altimeter to find it. After a while you sort of mechanically put the power in and get the rates of descent. To get the rates of descent under control, you make a fairly large input and then hold it for a second or two and take part of it out again and then cross-check the altimeter and display. It seemed to me that maybe 2 ft/sec is about as high as I would like to see or like to go with this thing. One time I had a fairly high rate of descent going and got down to about 12 ft on the altimeter. Was wondering whether I would be able to stop the rate of descent before touching down. Touchdown is about 9 ft. I still think there is some limitation here. It's probably a combination of limited thrust available plus aerodynamic damping and artificial damping. I can't differentiate; it's a combination, I think. As far as height control is concerned, you could do a fair job of flying the airplane. You can get adequate performance; is it satisfactory without improvement? Maybe you have some moderate pilot compensations to get the precision you want. There are again limits to how fast you can go up and down and still be able to control the rate of climb or the rate of descent. Precision of control, again, does take a certain amount of pilot effort to get the proper power setting, so frequency of collective input is maybe a little higher than you would like.

TABLE D-VI(b) (Continued)

Case CH5 $Z_{w_a} = 0$ $Z_{w_s} = -0.35$ $T/W = 1.02$ $Z_{\delta_c} = 8.00$ PR = 4

The hover performance was reasonable. Tried quite a few control sensitivities. I was having some lags in height control response to collective which I could improve by increasing the sensitivity. I had a tendency to then overcontrol, so I went back toward the lower sensitivity. I wasn't too happy with the precision of height control. Had to spend a fair amount of time at it and almost invariably when I did I had trouble trying to maintain my position over the spot. However, it was not really that horrendous. It was one of those configurations that, if the rates of change in height were kept to a low level, I was able to establish a steady-state height reasonably well, but again with quite a number of collective inputs. At the higher rates, did overcontrol quite a bit. When I reduced rates to fairly low levels, maybe a half-foot per second or something in that order, it gets reasonable as far as precision, with some effort you maybe can establish a hover height about ±5 ft. It's certainly controllable. I can get adequate performance with tolerable workload. I would think you should improve this some; I wasn't too happy with the precision of control only because it took quite a bit of effort, a lot of collective inputs to finally establish a steady-state hover height. I would probably think it's at least a moderate compensation required. I'm not really sure whether I ran out of thrust. Had the feeling that possibly at the higher rates it took a large amount of collective to stop the rate of sink.

Case CH6 $Z_{w_a} = Z_{w_s} = -0.05$ $T/W = 1.05$ $Z_{\delta_c} = 3.20$ PR = 6

Selection of the gearing was predicated primarily on reducing overcontrol tendencies. Ended up I think with the minimum gearing available. I had gone up fairly high with it; however, there is a very strong tendency to overcontrol, so I was going up and down like a yo-yo for a while. I was spending a fair amount of time on the height control when I was trying to be precise with it; that deteriorated the performance on the X-Y plane. The overall impression is that it is not a very good configuration. I suspect that it's a damping problem primarily, but I couldn't care less whether it is damping or the fact that I may have lags in the power application, or that there is a lack of excess thrust available. The end result is the same. The precision of height control is just not there. I could probably land it as long as I can keep the rates down. Have to work pretty hard, though, to establish exactly 20 ft or exactly 40 ft within, say, ±2 ft; that's a fairly difficult task. It does warrant improvement. It has very objectionable but tolerable deficiencies. Adequate performance requires extensive pilot compensation.

Case CH7 $Z_{w_a} = Z_{w_s} = -0.175$ $T/W = 1.05$ $Z_{\delta_c} = 1.51$ PR = 5.5

I didn't change the sensitivities on collective, just accepted what I had, mainly because it seemed adequate. I did a little better in hover, but I'm still having tough time flying longitudinal and lateral modes so I concentrated more on the hover in evaluating the height control. It's a matter of rates, I think. If I keep the rates reasonably low, I have some precision. If I try to speed up the response, I'm way behind the airplane in trying to recover it. I think the objectionable features are the lead time required in stopping the motion once you get it moving, the lag in getting some noticeable movement when you make the input and the fact that the precision of control in all axes was rather poor. If I set up high rates of descent and high rates of climb, then the precision just isn't there. You get an overshoot of at least 10 ft or more in the climb direction. I'm a little more hesitant to allow it to drop below 20 ft so I tend to make sharper, faster, larger inputs when the rate of descent is fairly high and I'm approaching 20 ft. It's like bang-bang control, you just put it in and say take some of it out because you know you probably have overcontrolled. Think it is controllable. Adequate performance with a tolerable workload? Not if you're talking about the overall task.

Case CH8 $Z_{w_a} = Z_{w_s} = -0.25$ $T/W = 1.05$ $Z_{\delta_c} = 1.51$ PR = 3

It is still not very good, but I managed to hover .. times almost within the square, which is pretty good. The same things bother me in longitudinal and lateral control: the lags, the turbulence, possibly the gearing is involved in there also. On the precision of vertical control, I was able to go down to 20 ft and hold it there while I attempted to do some maneuvers, went back up to 40 ft and hit it fairly well. For long periods of time the height control required no attention. Also attempted some high rates of descent and climb. The time that I have to concentrate on the height control is fairly minimal. Precision of height control was pretty good and the fact that you can pretty much set the collective and the height stays fairly close to where you put it, certainly within the 5 ft; that's pretty good. It seemed that there was always somewhat of a lag, but I think that's probably built into the altimeter. Possibly some of this hunting for the proper collective position may be caused by that lag in the altimeter. Only minor or minimal pilot compensation required.

Case CH9 $Z_{w_a} = Z_{w_s} = -0.05$ $T/W = 1.10$ $Z_{\delta_c} = 5.44$ PR = 7.5

I played around with the collective sensitivity quite a bit and was not able to find anything I liked. As I increased the sensitivity, I overcontrolled very badly. I had started out with the sensitivity to the minimum position on the lever and went up just a little, but that gave me all kinds of trouble. I picked something halfway between. I was still having troubles so I finally settled on having minimum sensitivity and that still gave me the same kinds of problems I had on the previous configuration (CH1) except more accentuated. To get the thing moving it seems to take quite a bit of thrust; once you get it moving, though, to stop it takes quite a bit of collective change so I suspect we have some degradation in the height damping, plus the fact that possibly we have low excess thrust available for height control. End result is that performance on the tasks, longitudinal and lateral, was quite bad. Didn't even try the lateral displacements; I was having enough trouble with pitch.

TABLE D-II(b) (Concluded)

Used a good portion of time just trying to keep the airplane at proper altitude or at least trying to stay close to the 20 ft or 40 ft altitude. I was overshooting at least 10 ft. Have a tendency to fly tighter when I'm going down than when I'm going up. Main objection was that I did not have precision of height control. I think there were times when I did manage to have the power lever just about right but then every time you maneuver the airplane to some extent you do have quite a bit of activity with the collective.

Case CH10 $\quad Z_{w_a} = Z_{w_c} = -0.125 \quad T/W = 1.10 \quad Z_{\delta_c} = 1.51 \quad PR = 5$

The initial control sensitivity on the collective was a little high and I overcontrolled very badly, so I cut the sensitivity down some. Was having more problems with hover than anything else on this configuration. Seems to be substantial lead required both in pitch and roll but it's more obvious in the pitch axis. The dynamics are also a problem. I had to make reasonable number of collective inputs to maintain 40 ft. However, it seemed to be a reasonable task. On the other hand, when I started to make climbs and descents to about 20 ft and back up to 40 ft, still had a tendency to overcontrol with the collective because there seemed to be a lack of thrust or there was a lag in the response of the thrust; either way you would get the same effect. Overall performance of the tasks was quite poor, especially the hover; I really had trouble with that. As long as I did things at reasonably low rates, I could manage to do the task. If I tried to push the airplane and force it to respond at higher rates, then everything seemed to go to pot. I don't really think I could do a quick stop with this thing too well. I didn't try any turns over the spot. Precision of hover, I thought, was quite poor and I had difficulty in establishing reasonable rates of descent and climbs so I could stop the height exactly where I wanted it. I think it was probably adequate for vertical landing as far as height control was concerned, but I'm not too sure about being able to hit a spot with any degree of precision. Control activity was quite large; I was continuously making inputs. Overall, there wasn't anything I particularly liked about it, but I thought it was flyable with a fairly large amount of effort. It takes quite a bit of concentration.

Case CH11 $\quad Z_{w_a} = Z_{w_c} = -0.175 \quad T/W = 1.10 \quad Z_{\delta_c} = 6.30 \quad PR = 3$

Don't have the feeling I have very precise control of the aircraft; however, I managed to keep reasonable control. It's just concentrating on height control that's a problem. By using low rates for take-off and changing altitude by 20 ft from 40 ft to 20 ft and back to 40 ft, did seem to have reasonable precision within about 1 or 2 ft. However, I did do a couple of maneuvers where I increased the rates fairly high and did have some overshoot problems. Got the impression that it was because I needed more collective displacement than I would normally like to use; it seemed I was using quite a bit of power. The excess power available is not as much as I would like. I don't think it was associated with damping per se because generally I could stabilize pretty well at 40 ft and 20 ft with just a moderate amount of hunting. Objectionable feature - I think it was just at the higher rates; too much collective displacement was required. Favorable features were that, by keeping the rates reasonably slow, I was able to have pretty precise control of altitude. No special piloting techniques except that, because of lags in the lateral and longitudinal dynamics, you have to lead the power application if your rates of descent or rate of climb get too high. It's hard to say exactly what those rates are, but if you're going to change 20 ft in more than about 30 sec, then you may get into some power application problems. I suspect it was probably lack of sufficient excess thrust available for control.

APPENDIX E

CONTROL-MOMENT EXCEEDANCE PLOTS FOR THE MANEUVERING SUBTASK

Pitch, roll, yaw and height control power exceedance data computed for a range of reference moment levels are contained in this Appendix. Initially, exceedance plots are present for pitch, roll and combined pitch and roll control moment data measured during the maneuvering subtask. The effects of turbulence intensity, aircraft speed stability and drag parameter, level of aircraft pitch and roll dynamics, control lags, rate and control coupling, and independent thrust-vector control can be seen in these exceedance data. The change in thrust-usage exceedance values with height velocity damping are presented next, and the final figure in this Appendix contains the yaw control-moment-usage exceedance results. In general, the effects of the different parameters examined on control-power usage, as defined by the exceedance data in this Appendix, are consistent with the effects noted (for the maneuvering subtask) by comparing the 5-percent exceedance levels.

RMS TURBULENCE INTENSITY, FT/SEC	3.4	5.8	8.2
SYMBOL	○	□	△

CONFIGURATION BC1 $M_u g = -L_v g = 0.33$ MANEUVERING SUBTASK

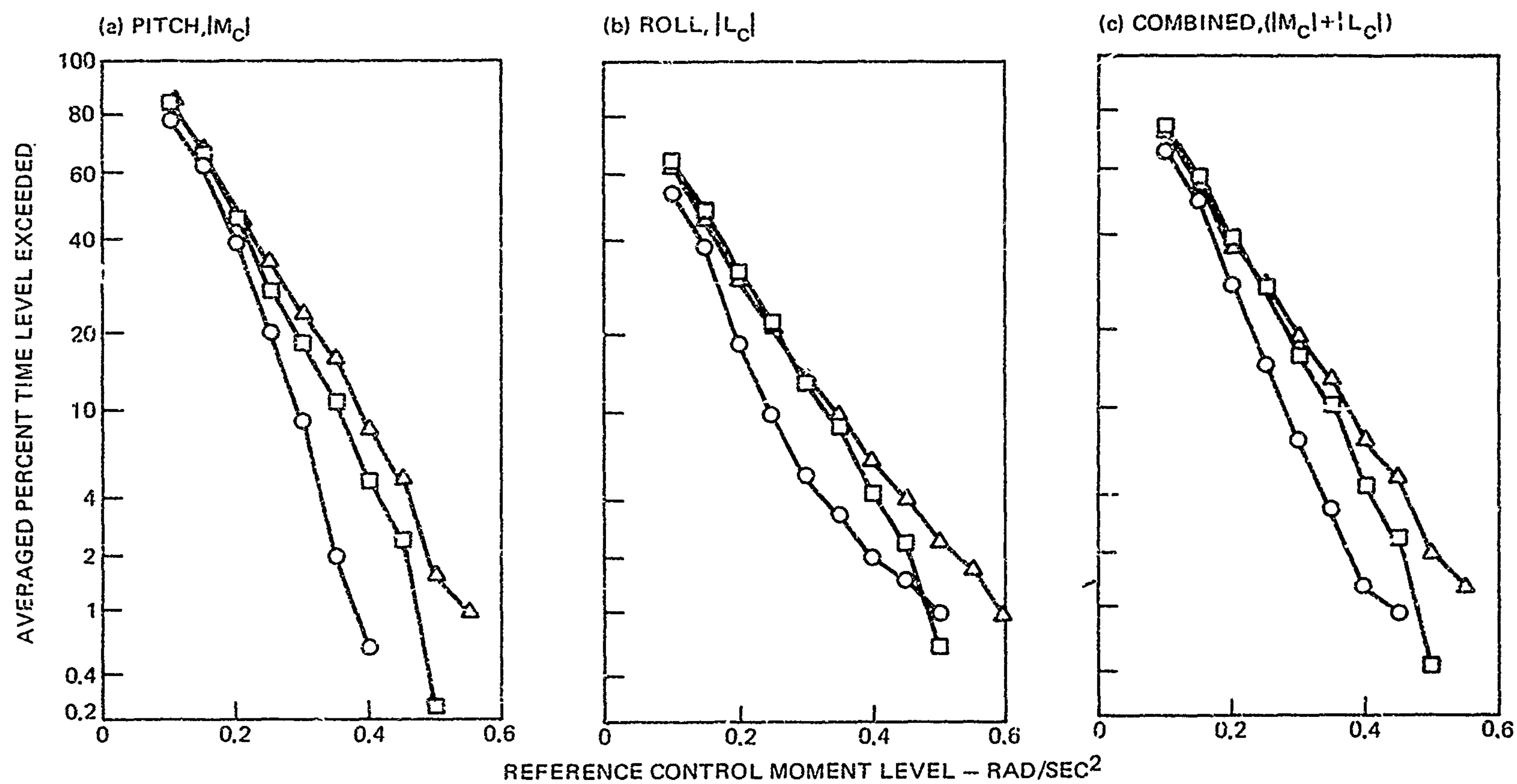

FIGURE E-1. Effect of Turbulence on Exceedance Results for a V/STOL Configuration with Small Response to Turbulence

RMS TURBULENCE INTENSITY, FT/SEC	3.4	5.8	8.2
SYMBOL	○	□	△

CONFIGURATION BC6 $M_{u}g = -L_{v}g = 1.0$ MANEUVERING SUBTASK

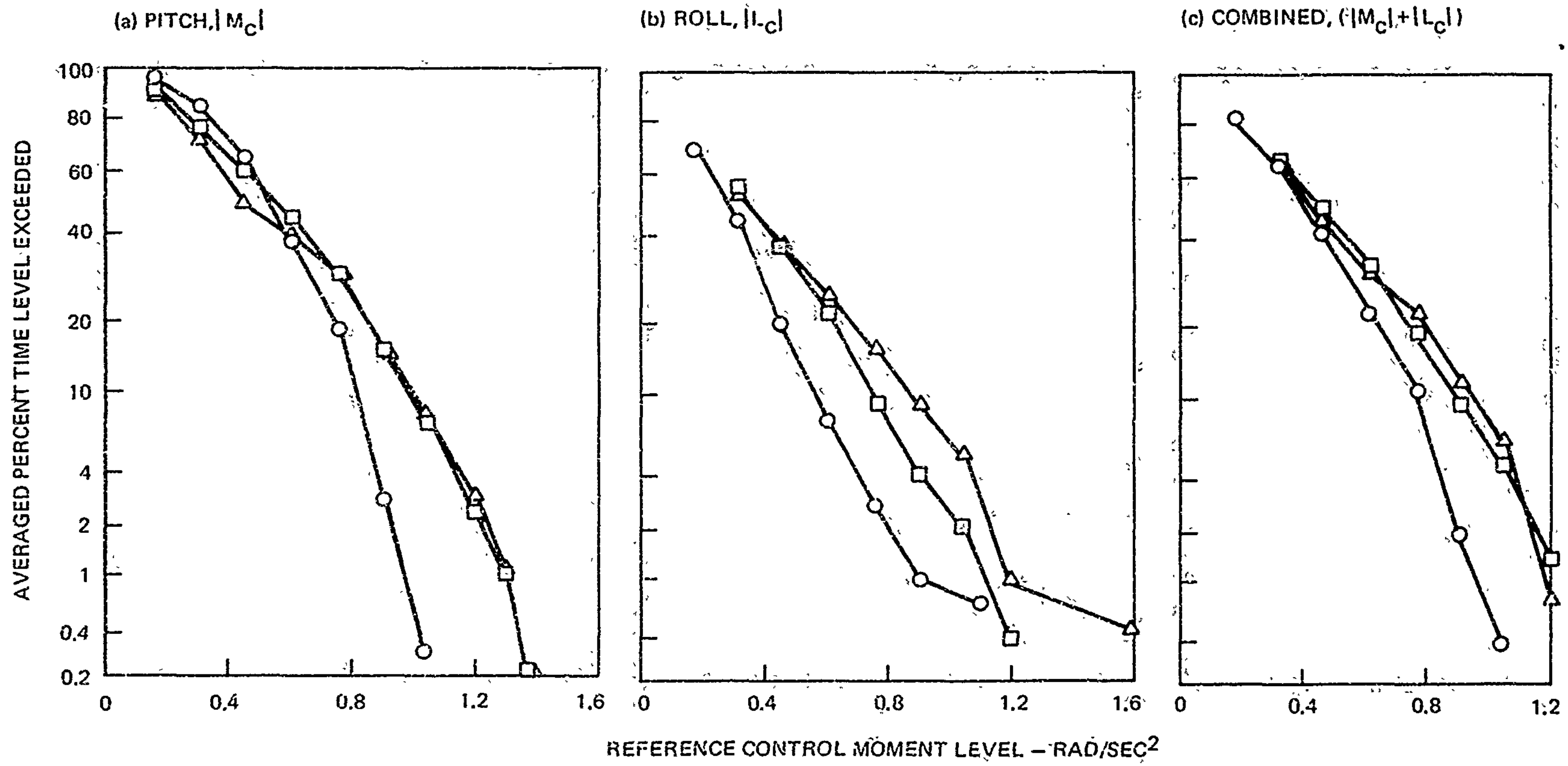

FIGURE E-2. Effect of Turbulence on Exceedance Results for a V/STOL Configuration with Large Response to Turbulence

BASIC CONFIGURATION	BC5	BC4
$M_{u_g} = -L_{v_g}$	0.33	1.0
SYMBOL	□	○

$\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC MANEUVERING SUBTASK

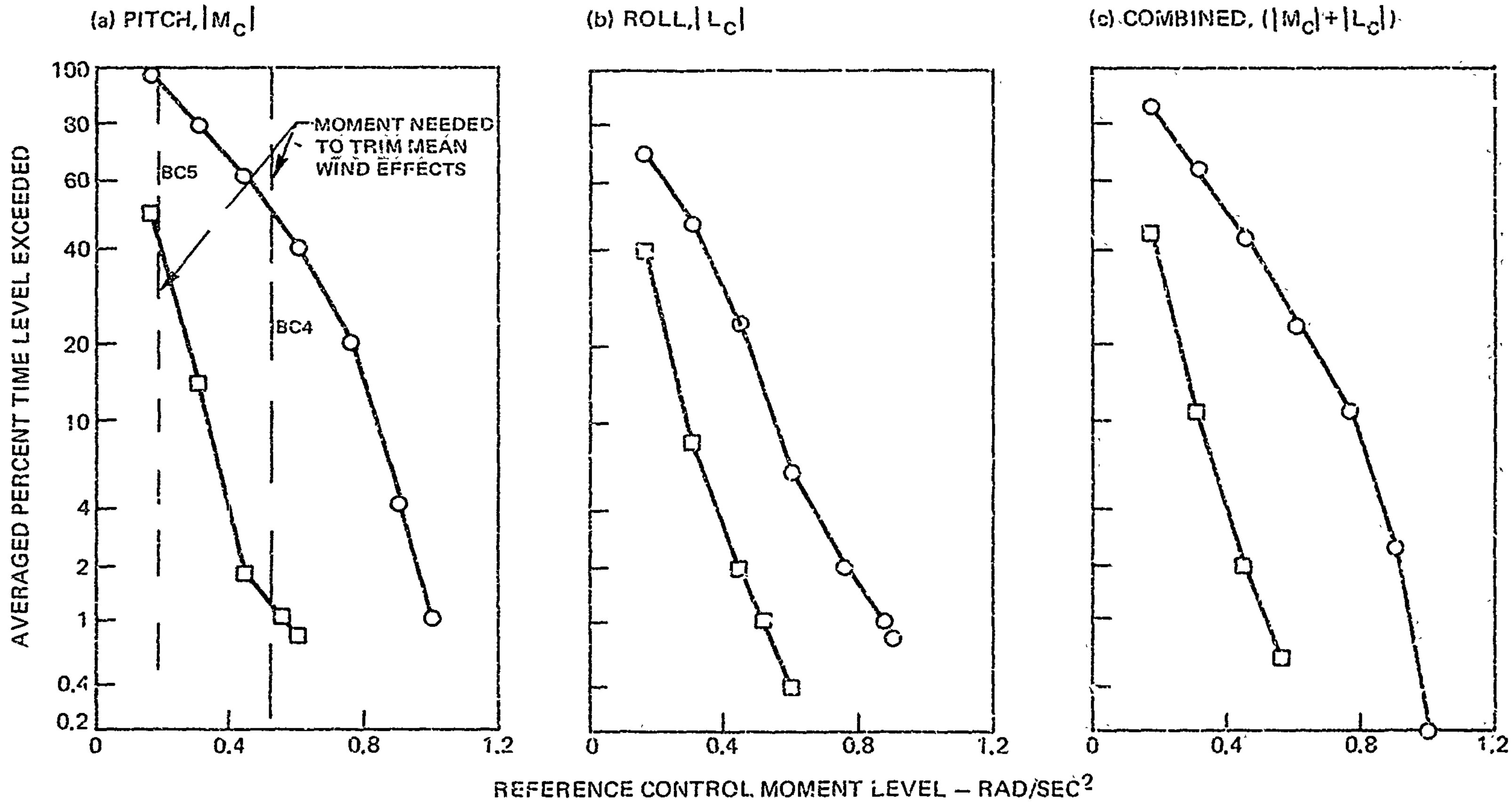

FIGURE E-3. Exceedance Results Showing the Effect of Aircraft Speed-Stability Parameters

BASIC CONFIGURATION	BC1	BC5
$X_u = Y_v$	−0.05	−0.20
SYMBOL	○	□

$\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC

MANEUVERING SUBTASK

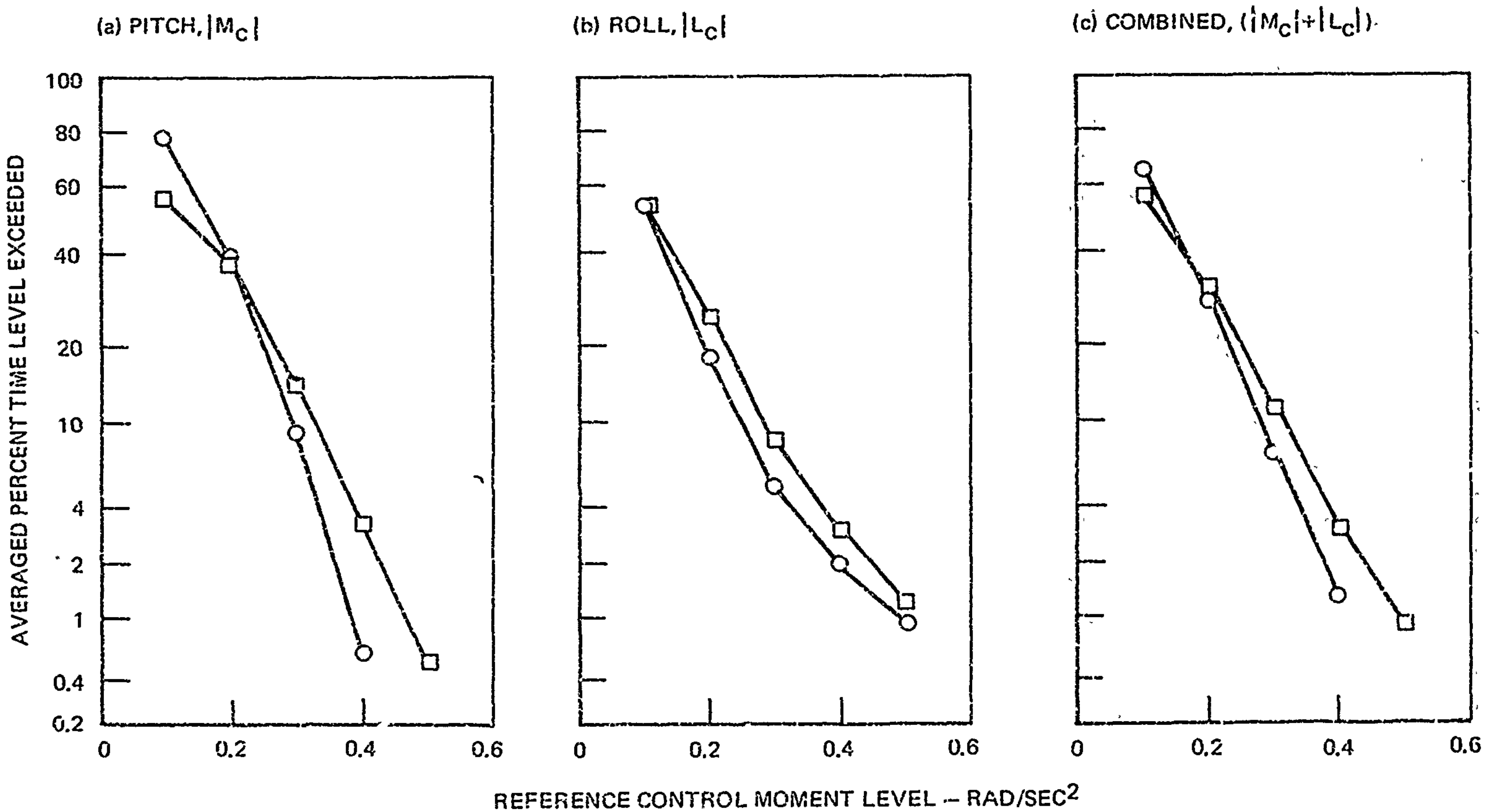

FIGURE E-4. Exceedance Results for V/STOL Configurations Having Different Drag Parameters

LEVEL	1	2	3
BASIC CONFIGURATION	BC4	BC2	BC3
SYMBOL	○	□	△

$M_u g = -L_v g = 1.0$ FOR BC4, BC2, BC3 $\qquad \sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC $\qquad$ MANEUVERING SUBTASK

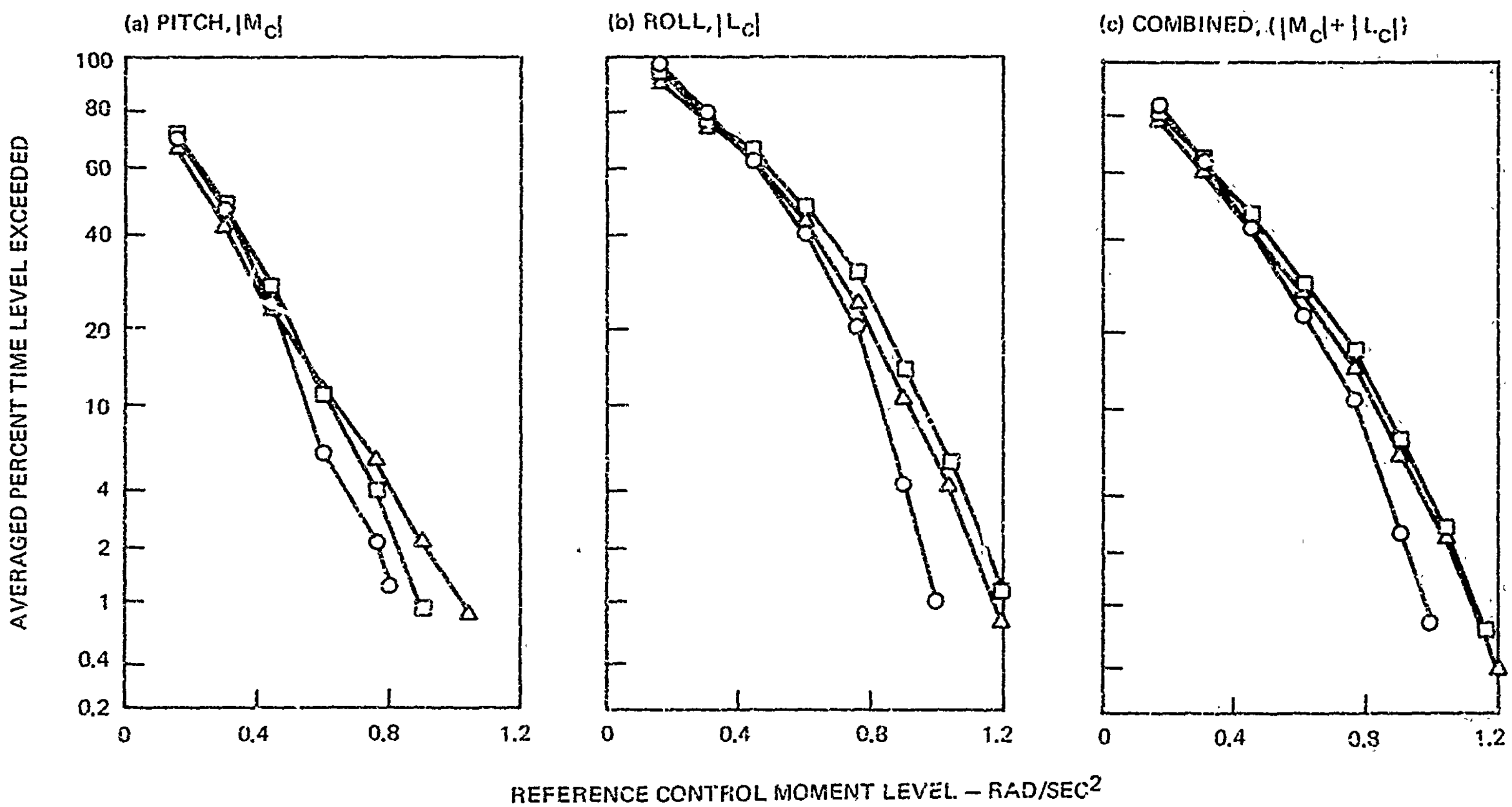

FIGURE E-5. Exceedance Data for Three V/STOL Configurations Exhibiting the Three MIL-F-83300 Levels of Flying Qualities

CONTROL LAG	0	0.3	0.6
SYMBOL	○	□	△

CONFIGURATION 3C4 $M_{ug} = -L_{vg} = 1.0$ $\sigma_{u_g} = \sigma_{v_g} = 3.4$ FT/SEC MANEUVERING SUBTASK

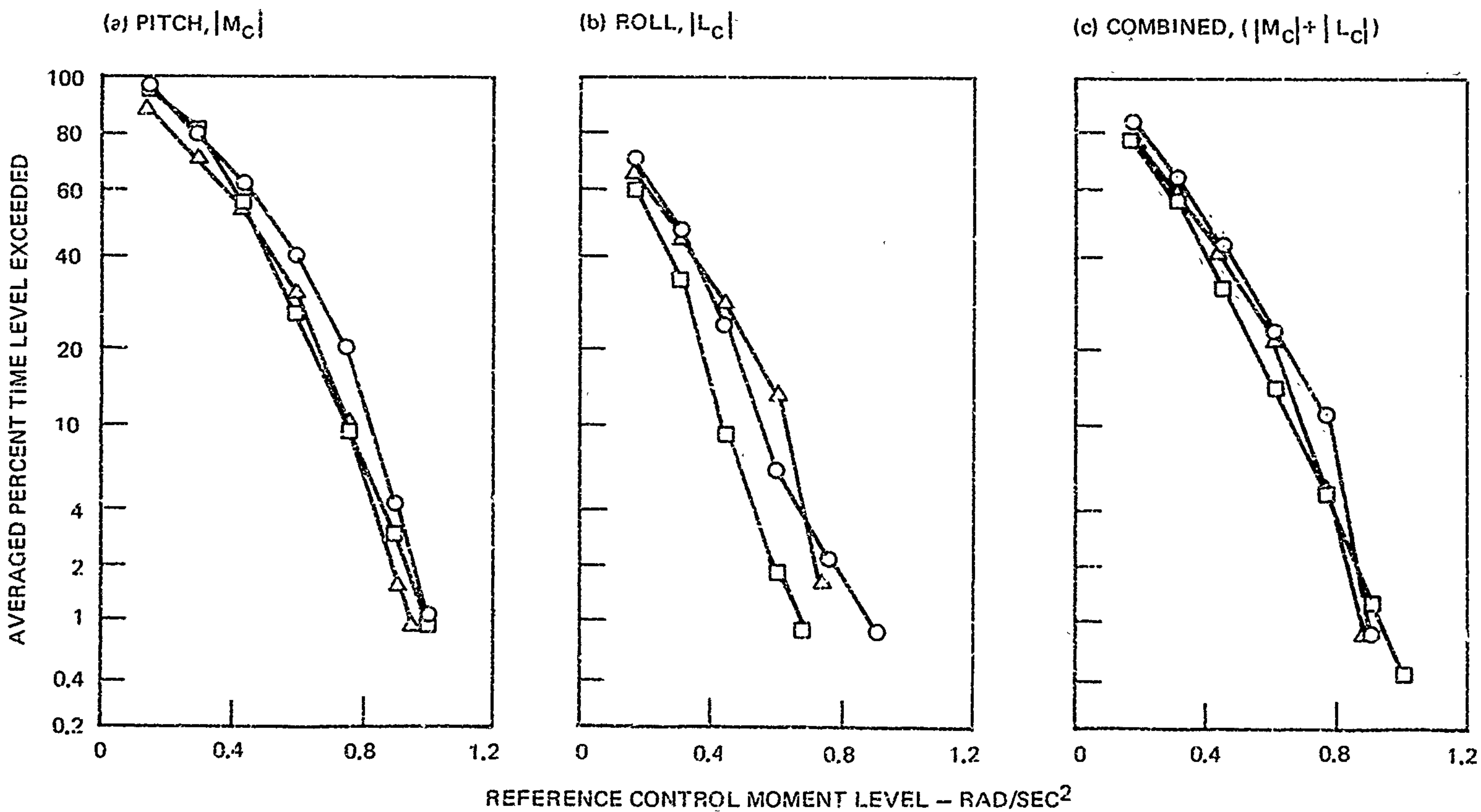

FIGURE E-6. Effects of Control Lags on Exceedance Results for a Configuration with Moderate Response to Turbulence

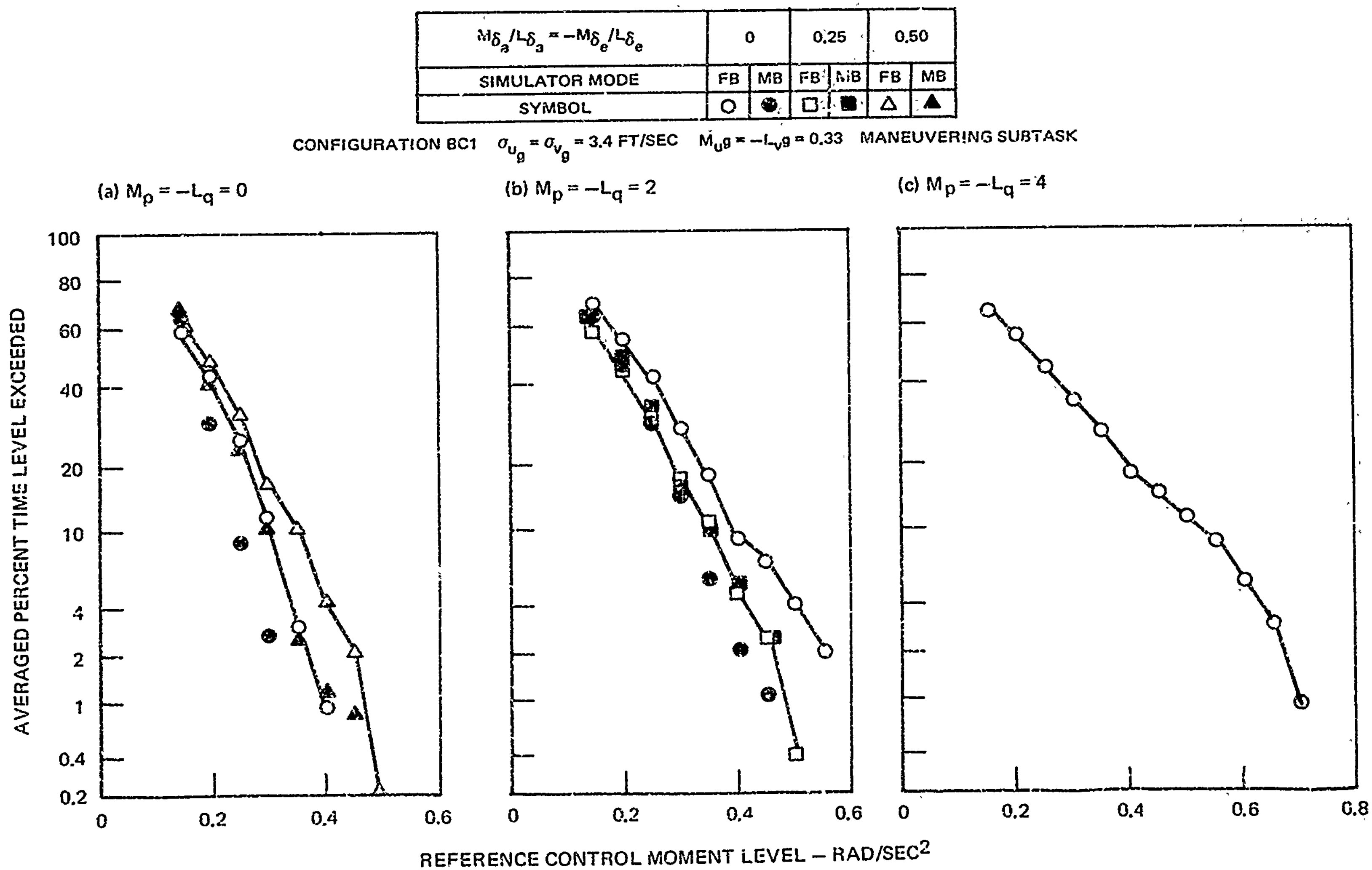

FIGURE E-7. Effect of Rate and Control Coupling on Pitch Exceedance Results

TYPE OF POSITION CONTROL	CONVENTIONAL	INDEPENDENT THRUST-VECTOR CONTROL
SYMBOL	○	□

FIXED BASE MANEUVERING SUBTASK

THUMB-SWITCH THRUST-VECTOR CONTROL, $\dot{\gamma}$ = 20 DEG/SEC, AND CONTROL-STICK ATTITUDE CONTROL FOR INDEPENDENT THRUST-VECTOR CONTROL

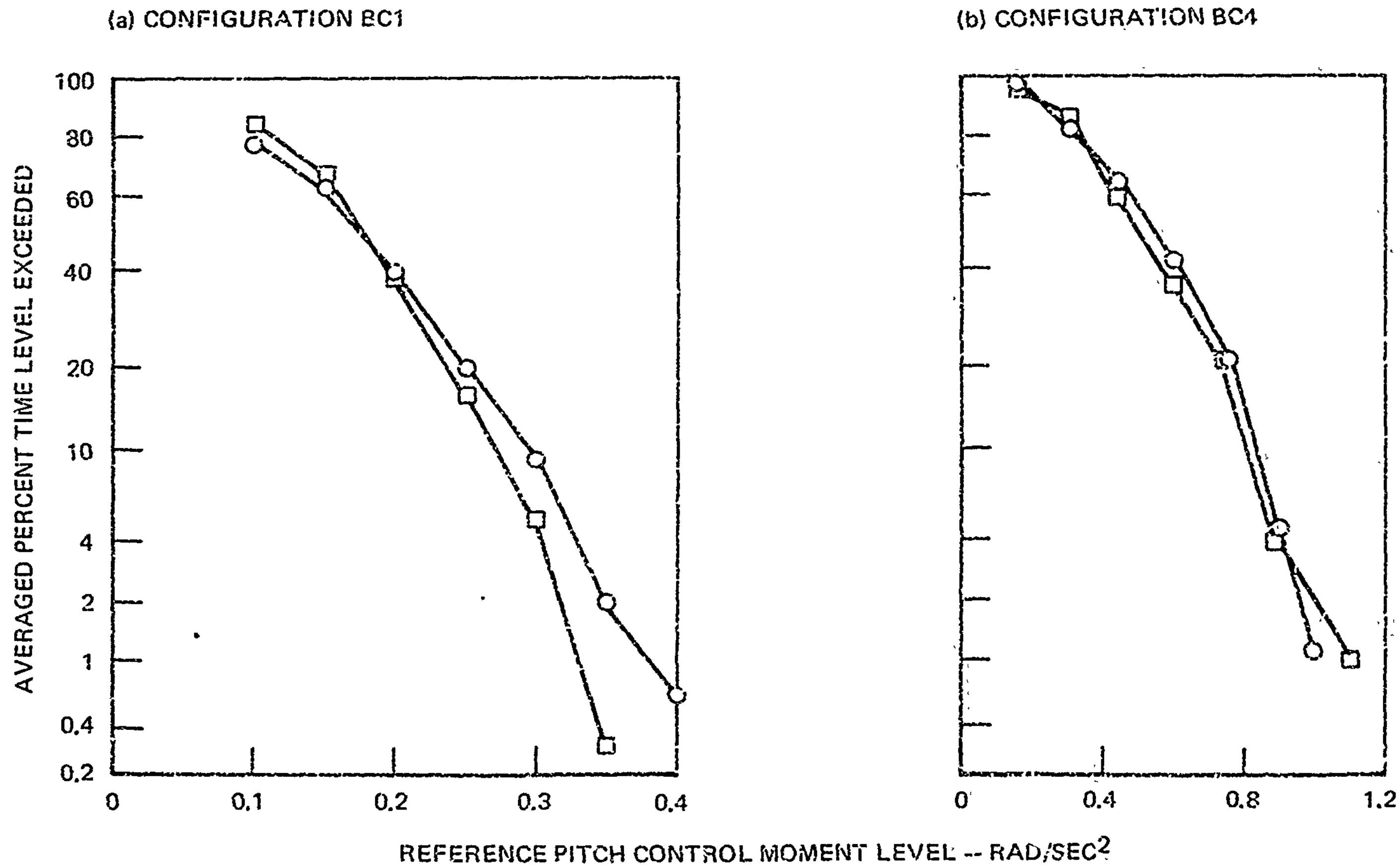

FIGURE E-8. Comparison Between Pitch Control-Moment Exceedance Data for Independent Thrust-Vector Control and Conventional Position Control

LEVEL OF Z_{w_T}	0	-0.25	-0.50
SYMBOL	○	□	△

$Z_{w_T} = Z_{w_a} + Z_{w_s}$ WHERE $Z_{w_a} = Z_{w_s}$ T/W > 1.15

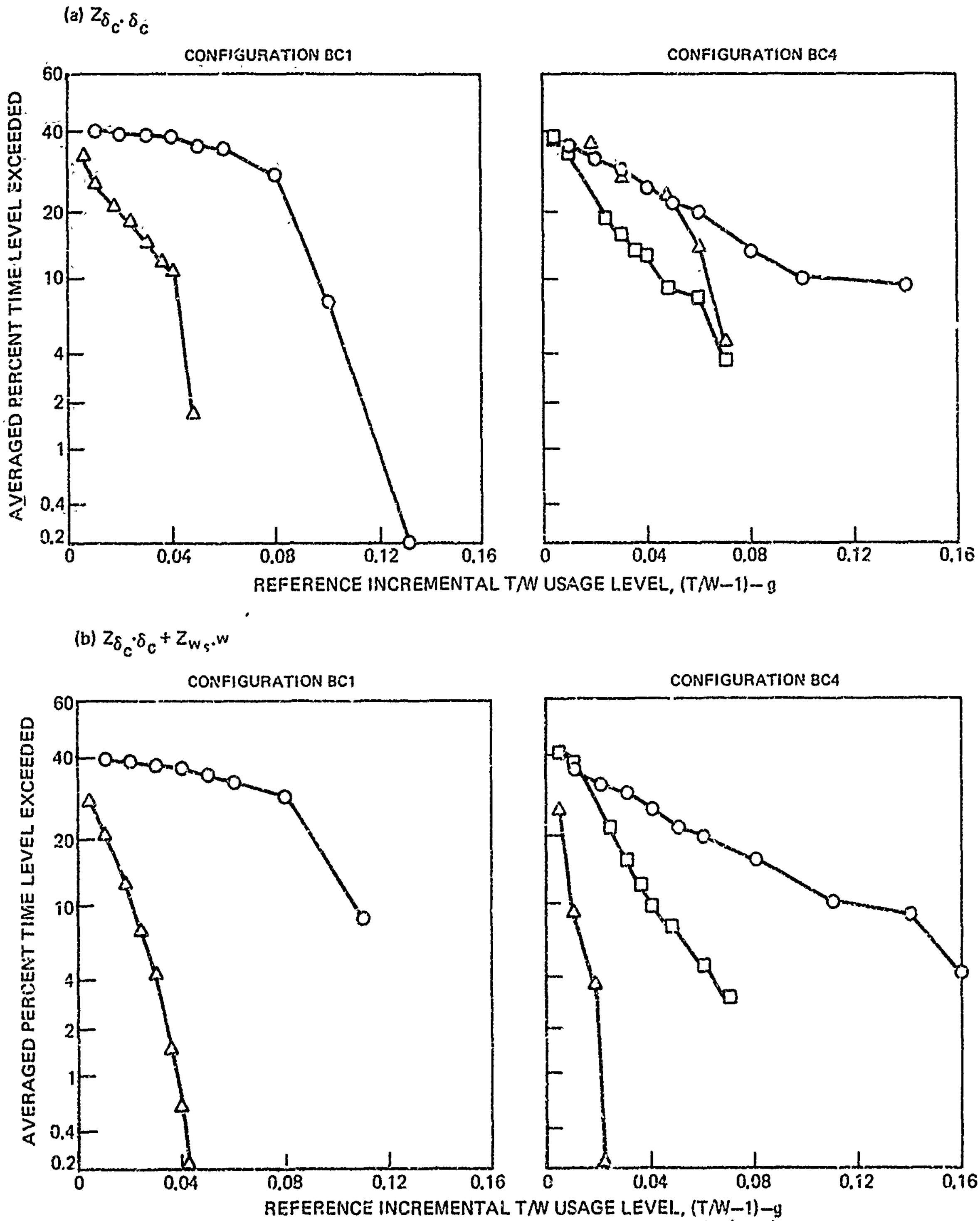

FIGURE E-9. Effect of Z_{w_T} on Incremental Thrust, (T/W-1), Exceedance Results Computed for Increased Thrust Commands

FIRST ORDER CONTROL LAG, τ_ψ	0	0.3	0.6
SYMBOL	○	□	△

TURN SUBTASK CONFIGURATION BC1 $N_v = 0.005$

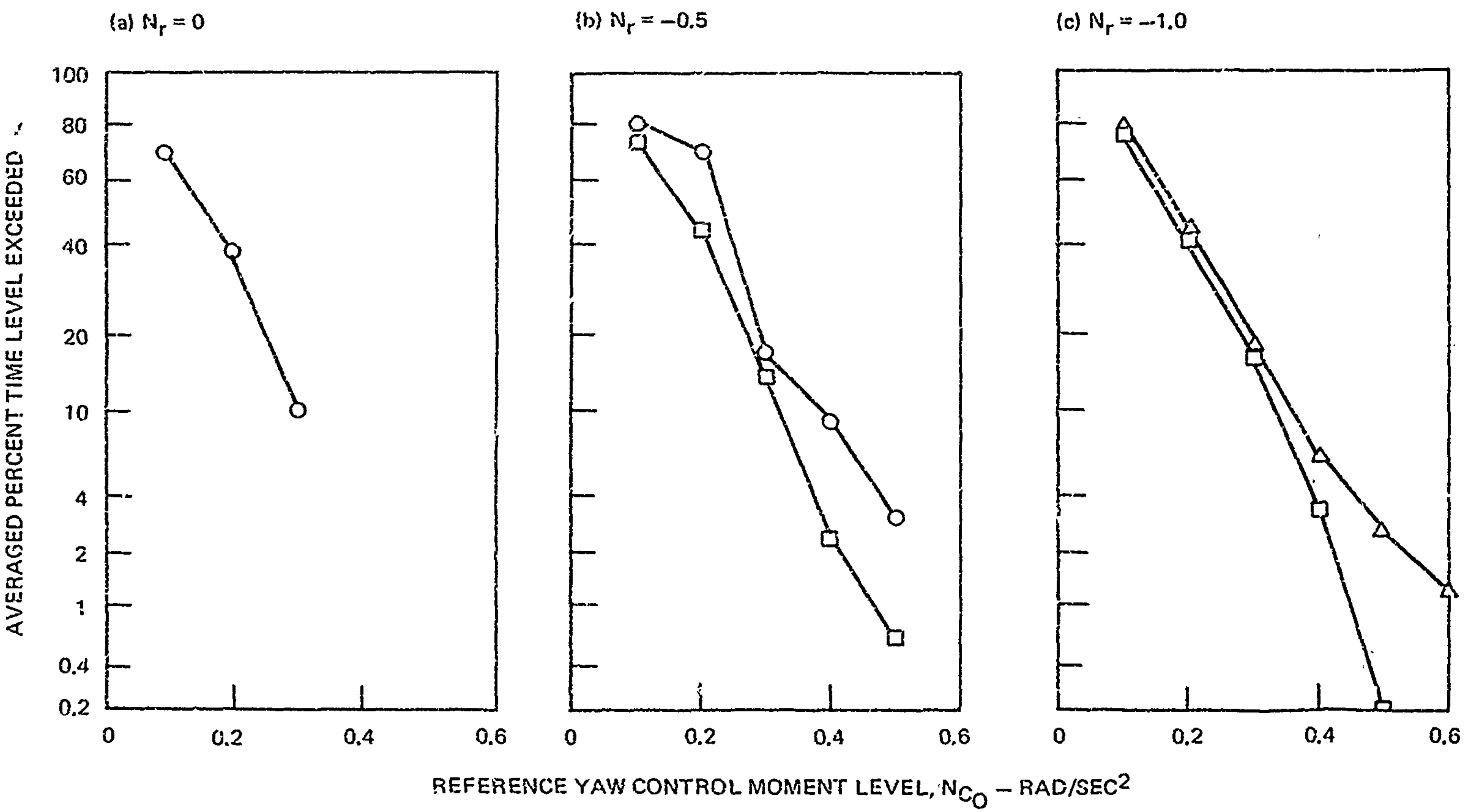

FIGURE E-10. Yaw Control-Moment Usage Exceedance Results

APPENDIX F

ADDITIONAL DETAILS OF THE UARL FLIGHT SIMULATION

This Appendix is a supplement to the description of the UARL flight simulation contained in this report (Section II.B). Details of the equations used to represent V/STOL aircraft motion in hovering and low-speed flight are discussed initially, here. The characteristics of the flight simulator controls are detailed next and the motion washout logic is described in the final section of this Appendix.

A. Equations of Motion

The general form of the six-degree-of-freedom perturbation equations of motion for V/STOL hovering and low-speed flight are given in Eq. (F-1).

$$\left.\begin{aligned}
&M_u u + M_\theta \theta + M_q q - \dot{q} = -M_{\delta_e}\delta_e - M_u\,(u_g + U_m \cos\psi)\\
&L_v v + L_\phi \phi + L_p p - \dot{p} = -L_{\delta_a}\delta_a - L_v\,(v_g - U_m \sin\psi)\\
&N_v v + N_r r - \dot{r} = -N_{\delta_r}\delta_r - N_v\,(v_g - U_m \sin\psi)\\
&X_u u - qw + rv - g\,(\sin\theta + \sin\gamma) - \dot{u} = -X_u\,(u_g + U_m \cos\psi) - X_{\delta_e}\delta_e\\
&Y_v v - ru + pw + g\sin\phi\cos(\theta + \gamma) - \dot{v} = -Y_v\,(v_g - U_m \sin\psi) - Y_{\delta_a}\delta_a\\
&Z_w w - pv + qu + g(1 - \cos\phi\cos\theta - \cos\psi\cos\gamma) - \dot{w} = -Z_{\delta_c}\delta_c\\
&\dot{\gamma} = 0.087\ TS\\
&\dot{\theta} = q\cos\phi - r\sin\phi\\
&\dot{\phi} = p + q\sin\phi\tan\theta + r\cos\phi\tan\theta\\
&\dot{\psi} = (q\sin\phi + r\cos\phi)\sec\theta
\end{aligned}\right\}\quad (F\text{-}1)$$

The various terms and symbols are described in the List of Symbols. The equations are for a body axis coordinate system and have been normalized with aircraft mass and moments of inertia. Stability derivatives on the left side of the equations describe the aerodynamic, propulsive and stability augmentation forces and moments. Terms on the right side describe the forces and moments induced by control inputs, the simulated turbulence and the mean wind. With the exception of N_v, the derivatives which couple motion between axes have generally been assumed to be negligible. However,

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pitch and roll rate coupling and control coupling were examined in one of the longitudinal and lateral control studies (Sections II.A.1.f. and III.A.5.). For this investigation the terms $M_p p$ and $L_q q$ were added to the left side of the pitch and roll moment equations, respectively, and the terms $M_{\delta_a}\delta_a$ and $L_{\delta_e}\delta_e$ were added to the right side of these respective equations. Also, it should be noted that the mean wind, U_m, was from 000 degrees true and it therefore affected the lateral and directional forces and moments, especially during the ±180 deg turn subtask. Finally, the relationship for $\dot{\gamma}$ describes the rate-command, thumb-switch control characteristic for the thrust-vector angle, γ. The parameter TS was either 0 or ±1 and, consequently, the pilot could command a 5 deg/sec rate-of-change of thrust-vector angle (or wing-tilt angle) to trim the effects of the mean wind acting on the aircraft longitudinal drag parameter. For the study of independent thrust-vector control the rate-of-change of thrust-vector angle was treated as a parameter (Section III.A.6.).

B. Characteristics of the Flight Simulator Controls

A conventional floor-mounted control stick (the cyclic pitch control stick of the S-61) was used for attitude control. It was used without a force gradient and the inherent friction present was negligible. The full longitudinal and lateral travels of the control stick were ± 6.63 in. and ±6.50 in., respectively. For height control, a conventional, floor-mounted helicopter-type collective control with adjustable friction was used (7.5 in. total travel). The rudder pedals (±3.2 in. total travel) for yaw control did not have a force gradient and the inherent friction was negligible. An on-off thumb-switch control was also used to command a fixed rate-of-change of thrust-vector angle (5 deg/sec). For the study of independent-thrust-vector control (Section III.A.6.) different commanded rates-of-change were considered. Also, for one part of that study the thumb switch was used to control pitch attitude and the cyclic stick controlled thrust-vector angle (Section III.A.6.).

C. Flight Simulator Motion Washout System

A schematic flow diagram for the motion washout interface between the simulated V/STOL aircraft motion (from the equations of motion implemented on an analog computer) and the commanded flight simulator motion is shown in Fig. F-1. This washout system insures that the flight simulator remains within its motion limits. The characteristics of the washout system have been tailored as much as possible to the frequency response features of the human vestibular system (Ref. 11). First-order roll-offs (20 dB/decade) are used to attenuate the low-frequency flight simulator attitude motion. This roll-off at low frequencies is similar to the frequency response of the attitude motion sensors in the vestibular system (the semi-circular canals). Second-order roll-offs are used for the translational motion.

Crossfeeds between low-frequency longitudinal and lateral accelerations and pitch and roll attitude, respectively, are used to simulate these accelerations with components of the earth's gravity vector. Because of this feature these low-frequency aircraft accelerations are also subtracted from the simulator translational motion commands. A more complete description of the washout system is contained in Ref. 11.

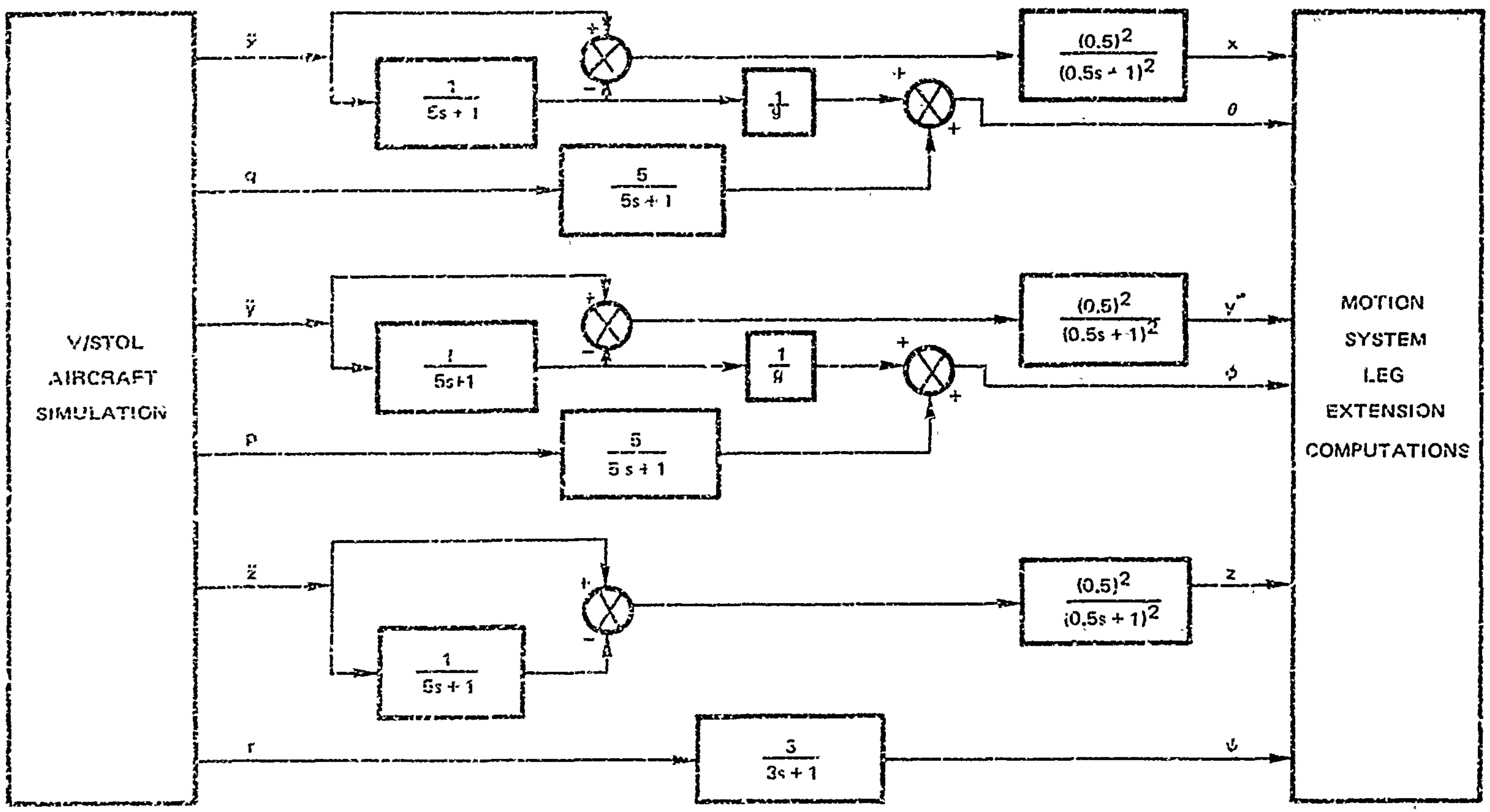

FIGURE F-1. Schematic Diagram of UAC V/STOL Flight Simulator Motion Washout System

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